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MINUTE CARCINOMA OF THE MAJOR BRONCHI

A FOLLOW-UP REPORT

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IN A paper read before the American Association for Thoracic Surgery on April 28, 1947, we cited, in abstract, two unusual case reports.[1] These concerned two patients in whom resectional therapy had been performed on the basis of a microscopic diagnosis of pulmonary carcinoma, made on examination of a specimen removed at bronchoscopy. A pneumonectomy had been performed on one patient; on the other, a middle lobe lobectomy. No carcinoma could be found in the surgical specimens, and, on postoperative bronchoscopic examination, there was no evidence of residual malignancy in the patient upon whom a lobectomy had been performed. As far as we were able to determine, these were the first such cases to be reported in the literature.

The patient upon whom a pneumonectomy had been performed has remained well for a follow-up period of six years. The subsequent history of the second patient warrants a complete case report.

CASE REPORT

M. W. (516547) was admitted to The Mount Sinai Hospital on Feb. 12, 1944, complaining of cough of two years' duration. Cough was occasionally paroxysmal in type, especially at night. There was virtually no sputum. Roentgenographic examination, performed on a number of occasions before admission, revealed a persistent shadow in the region of the right middle lobe. Bronchoscopic examination was performed, and a specimen removed from the right middle-lobe bronchus was reported as squamous-cell carcinoma (Fig. 1). On February 23, under cyclopropane-ether-intratracheal anesthesia, a thoracotomy was performed through an anterior incision. Numerous adhesions were found between the upper, middle, and lower lobes, as well as medially on the pericardium and anteriorly and laterally to the thoracic wall. The middle lobe was atelectatic; the upper and lower lobes were normal. No mass could be felt either in the middle lobe or at the proximal end of the middle lobe bronchus. The middle lobe was separated from the upper and lower lobes, and resected. Immediate examination of the specimen revealed no gross evidence of tumor. Therefore,

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an additional segment of the middle lobe bronchus was excised. This, too, did not contain any neoplastic tissue on gross examination nor upon subsequent microscopic examination. Because of doubt as to the advisability of performing any further resection, the bronchoscopist was summoned to examine the bronchial tree immediately. He could find no evidence of carcinoma in the bronchial tree. He removed a specimen from the middle lobe orifice, which was later reported as "Fragments of bronchial mucosa, showing chronic inflammation and a small area of cell atypism of the surface of the epithelium. No evidence of tumor."

Because of the absence of tumor in the surgical specimen and negative bronchoscopy (during operation), it was decided not to perform any additional resection. The stump of the middle-lobe bronchus was sutured, and the thorax closed with underwater drainage.

Postoperatively, an empyema developed. This was drained, following which convalescence was uneventful.

Pathologic examination of the surgical specimen was reported as follows: "The specimen consisted of a right middle lobe measuring 8.5 by 6 by 2 cm. The pleural surface showed a few fibrous adhesions near the hilum; otherwise it was smooth. The parenchyma was collapsed and bluish red in color. The bronchi were slightly widened; the mucosa was pale pinkish white and not thickened. The pulmonary vessels showed no changes. Separately received was a small piece of tissue containing segments of several bronchi. The mucosa of these was moderately reddened and slightly thickened."

Serial sections were cut from the right middle lobe bronchus for microscopic examination. No evidence of malignancy could be found. The final diagnosis was "right middle lobe, showing atelectasis and peribronchial and perivascular fibrosis." The original bronchoscopic specimen, upon which the diagnosis of squamous-cell carcinoma had been made, was reviewed by a number of pathologists, all of whom concurred in the diagnosis of carcinoma (Fig. 1).

On April 3, a phrenicectomy was performed to aid in obliteration of the empyema space, and on April 10, another bronchoscopic examination was performed. There was thick secretion in the right main and lower lobe bronchi. There was no recurrent flow. The right middle-lobe orifice showed a healed defect on its lower tip. The stump of the right middle-lobe bronchus had smooth walls and was closed at its lower end. There was some thickening of the lateral wall of the middle-lobe bronchus. A specimen removed from this area revealed "fragments of bronchial mucosa, showing metaplastic squamous-cell epithelium and a few isolated irregular cells. No evidence of tumor."

The patient was discharged on April 12, 1944, and remained under observation for several years. His cough persisted, but was no worse than it had been prior to operation. Roentgenographic examination of the chest showed no changes.

On Feb. 10, 1949, he was admitted to the Presbyterian Hospital, complaining of cough, anorexia, and a weight loss of 30 pounds. He stated that this cough had begun in 1947 and had become progressively worse. At times the cough was paroxysmal and associated with vomiting of blood. He also stated that he had had a pleurisy eighteen months before admission.

Physical examination revealed the signs of chronic illness. There were dullness and diminished breath sounds over the right lower lobe. The hemogram was within normal limits; the sputum was negative for tubercle bacilli on three examinations. Roentgenographic examination of the chest showed a 4 by 3 by 4 cm. mass at the right hilum.

Bronchoscopy performed on February 21 was reported as follows: "Just below the carina there was marked thickening of the mucous membrane and superficial ulceration of the right main bronchus. The thickening caused some narrowing of the bronchus. The lesion did not appear to be a tumor in that there was no fixation or rigidity." A specimen removed for biopsy revealed carcinoma. Exploratory thoracotomy was advised, but the patient left the hospital on March 4.

He did not return until July 19, when he was readmitted. At that time his general condition was unchanged. Bronchoscopic examination revealed that the carcinoma was

thickened, irregular, and ulcerated. The same process was present in the trachea, opposite to, and above, the carina, extending from the previously described lesion in the right main bronchus.

The carcinoma now was inoperable, and radiation therapy was administered from July 23 to August 17. In December, 1949, roentgenographic examination showed an increase in the size of the mass at the right hilum.

He was again admitted to the Presbyterian Hospital on Feb. 16, 1950, with metastases to the cervical and axillary lymph nodes and questionable metastases to the cervical vertebrae. The alkaline phosphatase was 8.8. He was discharged on March 25, and testosterone was prescribed.

This patient was next seen at Montefiore Hospital, where he was admitted on Sept. 17, 1950, in a preterminal condition. He rapidly deteriorated and died on September 27.

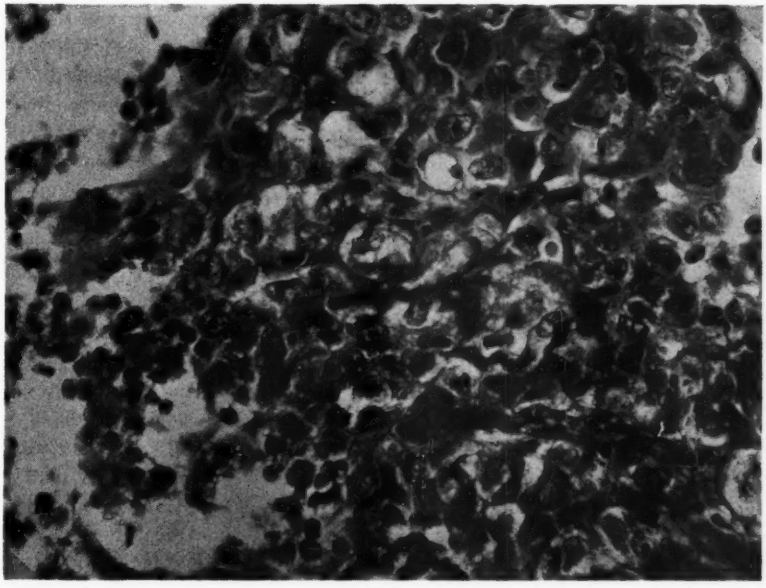

Fig. 1.—Photomicrograph of the specimen removed at the first bronchoscopy upon which the diagnosis of carcinoma was made.

Post-mortem examination revealed the following: anaplastic bronchogenic carcinoma of the right lung with extension to the trachea; metastases to heart, pancreas, liver, adrenals, kidneys, skeleton, lymph nodes of peribronchial, left axillary, and periaortic chains; focal pneumonia and focal fibrosis of the lungs. The lung was described as follows: "The distal one inch of the trachea presented a thickened granular mucosa which was markedly firm in consistency and slightly congested in areas. This granulation and thickening extended down into the right main-stem bronchus. The bronchi of the right lung could not be traced further than this point except for several in the lower lobe. The right middle-lobe bronchus was healed by a scar. A tumor mass occupied the lung around the hilum."

The occurrence of "minute" carcinoma of the lung has been described by Petersen, Hunter, and Sneeden.[2] Their specimens were in the parenchyma of the lung, but they believed that they arose from bronchial elements. "Minute"

carcinoma of the main bronchi have not been described, but it is evident that they may be present at some time in the development of a carcinoma.

Papanicolaou and Kropowska[3] have reported a carcinoma in situ of the right lower bronchus. Although four specimens of sputum and six bronchial washings were positive for carcinoma cells, bronchoscopy was negative. The patient died from emphysema, anoxemia, and lobar pneumonia. Gross examination of the lungs revealed no evidence of malignancy. On careful examination with many serial sections of the bronchial tree, a minute epidermoid carcinoma in situ was found in the bronchus of the right lower lobe.

Despite the definite bronchoscopic diagnosis of malignancy made in both of our cases, we originally reported them with some hesitancy because of the inability to substantiate the diagnosis by the finding of the carcinoma in the resected specimens. In the patient upon whom lobectomy was performed, there was the possibility that the actual site of the tumor had not been removed. Postoperative bronchoscopic examination, with removal of a specimen from the stump of the middle-lobe bronchus, still failed to reveal any evidence of malignancy. The subsequent course of this patient, with development of a carcinoma a number of years later, apparently proves the correctness of the original diagnosis. The tumor was undoubtedly one of slow growth and, as is so often seen in pulmonary malignancy, did not cause symptoms until the later stages. It is most likely that if a pneumonectomy had been performed instead of a lobectomy the patient would have been cured of a pulmonary carcinoma, as was the other patient, who has remained well for six years.

The thoracic surgeon must rely completely upon the pathologist's diagnosis made on the microscopic examination of specimens removed during bronchoscopy. It has been our experience that when, prior to surgery, a *definite* diagnosis of malignancy is made on examination of a specimen removed during bronchoscopy, it has invariably been substantiated (except in the cases cited) by later examination of the surgical specimen. On occasions, the pathologist is not able to make a definite diagnosis, and then additional bronchoscopy or exploratory thoracotomy is indicated. In both of our patients, the diagnosis of malignancy was a definite one and concurred in by every pathologist who examined the slides.

SUMMARY AND CONCLUSIONS

A follow-up report of two cases previously cited is presented.

Bronchoscopic specimens in both cases were reported as carcinoma. One patient had a pneumonectomy, and has remained well for six years (no carcinoma could be found in the resected lung). At operation on the second patient, no gross tumor was found, and bronchoscopy during the operation revealed no evidence of disease. Therefore only a lobectomy was performed. Subsequent bronchoscopy was also negative. Five years later, clinical symptoms appeared, and bronchoscopy revealed a carcinoma of the main bronchus of the lung previously operated upon. The patient died six and one-half years after the original diagnosis had been made.

If the pathologist makes an unequivocal diagnosis of malignancy upon examination of a specimen removed from a major bronchus, the surgeon should perform a pneumonectomy even though no gross evidence of malignancy is found at operation.

We wish to thank Dr. William Stearns for permission to use the records of the Presbyterian Hospital, and Dr. Harry M. Zimmerman for the use of the post-mortem records of Montefiore Hospital.

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MINUTE PERIPHERAL PULMONARY TUMORS

A Study of Eight Cases

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THE discovery of clinically unsuspected pulmonary neoplastic disease in routine autopsy and surgical material is a very infrequent occurrence. This may be partially explained by the fact that the parenchymatous tissue of the lung does not lend itself readily to visual examination, with the result that the pathologist is forced to depend largely on palpation for the identification of diseased areas. Furthermore, despite the large volume of the organ, relatively few blocks often taken in haphazard fashion are usually removed for microscopic study. These limitations associated with the gross examination do not wholly account for the discovery of the tumors to be described below, since they all represented accidental microscopic findings and were undoubtedly too minute in size to be perceived with the naked eye.

We have collected eight of these pulmonary neoplasms, all identical in their microscopic appearance, and all representing incidental findings in our autopsy and surgical specimens. It is felt that the reporting of these cases will be of value, not only because of the small number of recorded instances of similar atypical cellular proliferation (Table I), but chiefly because our investigations have convinced us of their relatively benign character. This latter view finds support in a study by Womack and Graham,[1] but is in complete disagreement with the majority of those who have described similar epithelial overgrowths.[2-6]

MATERIAL

Six of our eight cases were incidental observations at autopsy of persons dying from a variety of causes, while the remaining two were from surgical specimens removed because of long-standing severe bronchiectasis (Table II). All tissue was fixed in 10 per cent formalin, and in addition to the usual hematoxylin and eosin stain, the sections containing tumor were stained with the following methods: Weigert van Gieson, Wilder's reticulum, McManus' periodic acid Schiff, and Lison's argentaffine techniques. Several of the blocks were serially sectioned in an attempt to trace the origin of the tumor and to gain some idea of its relative size. These sections were cut at a thickness of 6 microns, and as many as 225 sections were obtained from a single block.

REPORT OF CASES

Case 1.—L. A. (A44-242), an 81-year-old woman, who was a known cardiac with a history of bronchiectasis of several years' duration, expired from bronchopneumonia after a four-day illness. The chief findings at autopsy were bilateral bronchopneumonia, bronchiectasis, fibrosis and emphysema.

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TABLE I. PREVIOUSLY RECORDED MINUTE PULMONARY NEOPLASMS

DATE	AUTHOR	AGE (YR.)	SEX	CAUSE OF DEATH	GROSS PULMONARY DISEASE	LOCATION OF TUMOR
1921	Gray and Cordonnier	78	F	Fracture of femur	Calcified apical nodule	
1930	Karsner and Saphir				Bronchiectasis? Bronchiectasis	
1941	Womack and Graham	34	M		Congenital cystic disease	Left lung
1941	Womack and Graham	48	M	Congenital cystic disease		Left lung
1941	Womack and Graham	39	M	Congenital cystic disease		Right lower lobe
1943	Stewart and Allison	32	F	Alive and well	Bronchiectasis	Left lower lobe
1949	Petersen et al.	69	F	Carcinoma of cecum	Bronchopneumonia Purulent bronchitis Bronchiectasis	Left upper lobe
1949	Petersen et al.	54	M	Hypertensive cardiovascular disease	Bronchopneumonia	
1949	Petersen et al.	74	F	Bilateral pyonephrosis	Acute bronchitis Atelectasis	
1949	Petersen et al.	52	F	Generalized peritonitis	Bronchopneumonia Atelectasis Bronchiectasis	
1949	Petersen et al.	70	F	Bronchopneumonia Purulent bronchiectasis	Bronchopneumonia Purulent bronchiectasis	
1951	Spain and Parsonnet	95	F	Encephalomalacia	Bilateral subapical fibrosis Diffuse emphysema Enlarged hilar nodes	Both lower lobes Right upper lobe Hilar node

TABLE II. AUTHORS' SERIES MINUTE PULMONARY NEOPLASMS

CASE NUMBER	AGE	SEX	CAUSE OF DEATH	GROSS PULMONARY DISEASE	LOCATION OF TUMOR
1	81	F	Bronchopneumonia	Bronchopneumonia Bronchiectasis Fibrosis Emphysema	
2	48	F	Rheumatic heart disease	Bronchopneumonia	
3	47	F	Acute hemorrhagic pancreatitis	Lower lobe atelectasis	One lower lobe
4	64	F	Carcinoma of the cervix	Fibrosis, left apex Emphysema	Left upper lobe
5	68	F	Cerebral thrombosis	Bronchiectasis Thickened visceral pleura	
6	43	M	Alive and well	Bronchiectasis	Right lower lobe
7	30	F	Alive and well	Bronchiectasis	Left lingual lobe
8	70+	F	Heart failure Arteriosclerotic heart disease	Bronchopneumonia	Left lower lobe

CASE 2.—M. S. (A48-125), a 48-year-old woman with a four-year history of cardiac failure on a rheumatic basis, died following an embolism to the left lower extremity. At autopsy the principal findings were severe mitral stenosis, chronic pericarditis, recent splenic infarction and an arterial embolus in the left lower extremity. Examination of the lungs revealed bilateral bronchopneumonia.

CASE 3.—H. C. (A48-297), a 47-year-old woman with a history of gall bladder disease, was admitted to the hospital with a history of abdominal pain of four days' duration. Exploratory laparotomy disclosed an acute hemorrhagic pancreatitis, and the patient expired

a few hours after the surgery. Significant autopsy findings were a generalized peritonitis with fat necrosis, acute hemorrhagic pancreatitis, and an early lower nephron nephrosis. Slight bilateral lower lobe atelectasis was noted in the lungs.

CASE 4.—H. V. (A49-43), a 64-year-old woman, died as a result of advanced carcinoma of the cervix of two years' duration. At autopsy the chief findings were carcinoma of the cervix with extension to the bladder, rectum, ureters, and pelvic nodes. An acute bilateral pyelonephritis, and a terminal endocarditis of the mitral valve were present. Gross examination of the lungs revealed some emphysema and fibrosis in the left apical region.

CASE 5.—C. K. (C. I. H. A51-8), a 68-year-old woman, was admitted to the hospital for nursing care following a cerebrovascular accident five weeks previously. During her hospital stay she became incontinent, developed cystitis, pyelonephritis, and died in uremia. In addition to the urinary pathology, a large focus of encephalomalacia was noted at autopsy in the left cerebral hemisphere. Some bronchiectasis and thickening of the right visceral pleura were also described.

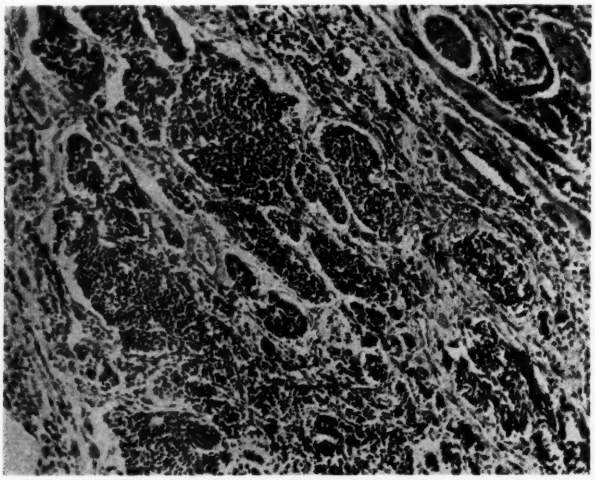

Fig. 1.—Case 7. Low-power view of the largest observed single area of tumor. Note the tendency of the cell nests to lie in spaces. Hypertrophied muscle bundles can be seen in the upper right corner. (×112.)

CASE 6.—C. S. (50-1880), a 43-year-old man, underwent a right lower lobectomy for severe bronchiectasis of seven years' duration. Gross examination of the resected lobe revealed a fusiform dilatation of the larger radicles of the bronchial system while the smaller branches were distended to form blind-end cysts. The patient had an uneventful convalescence and is alive and well at the present time (one year and a half after surgery).

CASE 7.—M. P. (50-2489), a 30-year-old woman, underwent a left pneumonectomy for bronchiectasis of two years' duration. Grossly the lower lobe and lingual bronchi and bronchioles were characterized by diffuse fusiform dilatations. A solitary 1 cm. calcified focus was noted at the apical portion of the lower lobe. The patient had an uneventful recovery and is alive and well at present (one year after surgery).

CASE 8.—M. S. (A51-81), a 70-year-old woman suffering from chronic congestive heart failure on an arteriosclerotic basis, was admitted to the hospital with a diagnosis of pulmonary infarction. The patient expired a few minutes following arrival, and at autopsy the significant findings were myocardial hypertrophy and fibrosis with severe sclerosis of the coronary arteries. Gross examination of the lungs disclosed bilateral lobular pneumonia and slight pulmonary edema. Bilateral chronic pleuritis was described.

PATHOLOGIC FEATURES

The tumor foci were readily apparent under low-power magnification, and were peripherally and usually subpleurally located. As will be noted in Table II, it was possible to further localize the tumor in only four cases, but it would appear that either lung and any lobe may be affected. The characteristic and constant microscopic pattern of these tumors consisted of sharply circumscribed epithelial nests enmeshed in a dense fibromuscular stroma (Fig. 1). These

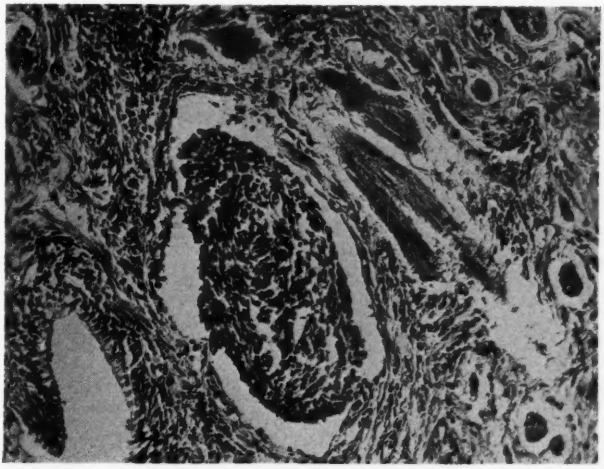

Fig. 2.—Case 7. Nest of tumor cells within a clear space showing points of penetration of the capillary stalks into the tumor. The adjacent muscle bundles are particularly prominent. (×170.)

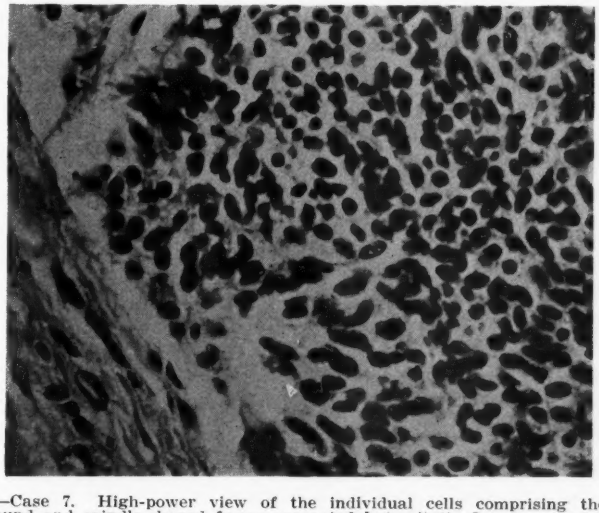

Fig. 3.—Case 7. High-power view of the individual cells comprising the tumor. A mixture of round and spindle-shaped forms are noted but mitotic figures cannot be identified. (×650.)

tumor nests varied somewhat in size, with 100 microns in diameter being an average size, and 250 microns the upper limit. A clear space separated the tumor nests from their surrounding stroma (Fig. 2), and most observers have regarded these spaces as lymphatic channels—a fact largely responsible for the impression that these neoplasms are malignant in nature. The individual cells composing the nests were characterized by prominent vesicular nuclei which were both spindle and round in shape (Fig. 3). Nucleoli were not discernible, and at no time were mitoses noted in any of the cells, including those tumors which were serially studied. The cytoplasm of the tumor cells was sparse, faintly acidophilic, and indefinite in outline. Blood capillaries and a small amount of collagen and reticulin fibers could be identified within many of the nests with the use of appropriate stains. The point of attachment of these connective

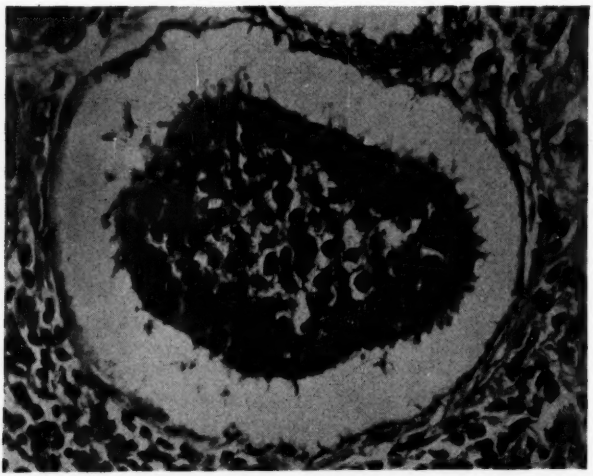

Fig. 4.—Case 6. "Sun-ray" appearance produced by shrinkage of the tumor nest away from its adjacent connective tissue. (×500.)

tissue stalks to the marginal stroma was sometimes noted (Fig. 2). It is our belief that these pseudolymphatic spaces are artificial in nature produced by shrinkage during the processes of fixation and embedding. This conclusion is supported not only by the demonstration of the vascular stalks and cores, but also by the fact that we frequently noted a definite "sun-ray" appearance at the nests' peripheries due to loss of cohesion between the outer cells and the adjacent connective tissue (Fig. 4). A second histologic pattern, observed in four of our cases, was an intrabronchiolar polypoid type of growth (Fig. 5). The cells comprising these masses were subepithelial in location, and cytologically identical with those described above within the fibromuscular stroma. The bronchiolar epithelium was continuous over these masses, but tended to undergo a transition to a flattened spindle-shaped type of cell (Fig. 6). In the study of serial sections we failed to find unquestionable evidence that these intrabron-

chiolar lesions arose from the covering epithelium, i.e., at no point was the covering epithelium composed of these tumor cells. Direct cellular continuity between these masses and the near-by stromal tumor nests could not be demonstrated.

In a consideration of the coexisting pulmonary pathology the cases will be divided into two general groups: those with bronchiectasis and those without

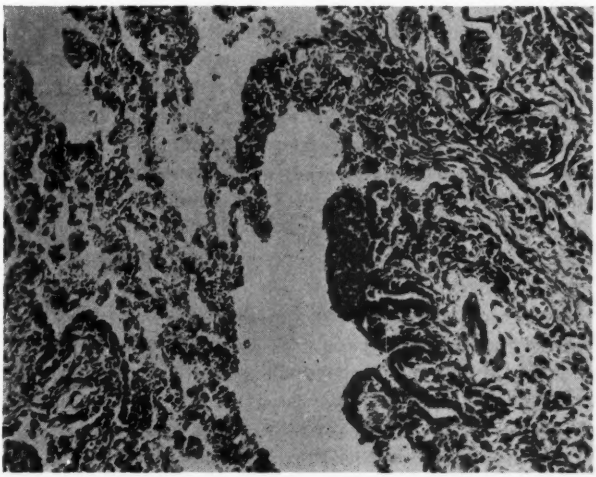

Fig. 5.—Case 8. Intrabronchiolar polypoid type of growth. This pattern was noted in four cases. (×200.)

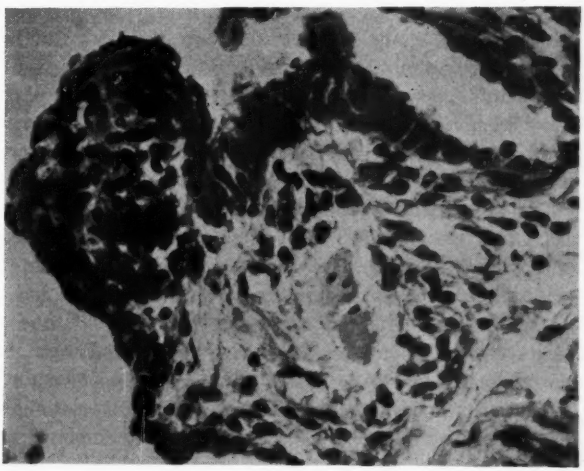

Fig. 6.—Case 7. Higher magnification of a polypoid mass within a terminal bronchiole. The transition from the normal low cuboidal epithelium to the spindle type of cell is striki.ng. (×650.)

it. The four bronchiectatic cases in the present series had the usual dilation of the bronchial system with acute and chronic inflammation in and about their walls. The bronchial lumens contained inspissated mucus, and the mucous membrane was intact and only rarely showed evidence of squamous metaplasia. The smooth muscle coat, although extensively infiltrated with lymphocytes and eosinophiles, was well preserved. The near-by bronchioles, some of which contained tumor and some with tumor immediately adjacent, were incorporated in a sclerosing fibrous tissue growth in which hypertrophied muscle bundles were frequently prominent (Fig. 2). This latter observation suggests that, in some of the cases at least, the tumor nests may be located at the sites of obliterated bronchioles. Where alveoli could still be recognized, marked atelectasis and occasional emphysematous foci were present. Chronic inflammatory cells were not always observed in these scarred areas. Tumor was noted in the fibrous tissue surrounding an intense deposition of anthracotic pigment in one case. The medium-sized arteries were the site of rather marked intimal fibrous tissue proliferation. It was possible to localize the tumors in only two of the four cases. The tumor foci were located in the right lower lobe in Case 6, and in the left lingual and lower lobes of Case 7.

The four cases showing no gross or microscopic evidence of bronchiectasis will be individually considered. Case 2, a cardiac patient, disclosed a bronchopneumonia of recent origin at autopsy. This case is of interest in that the one section in which tumor was recognized was a subpleural atelectatic focus at some distance from the pneumonic process. This solitary neoplastic area was surrounded by fibrous tissue and scattered areas of emphysema were observed. Obliterative endarteritis was also noted throughout the atelectatic zone. Case 3, dying as a result of acute hemorrhagic pancreatitis, showed some slight, apparently agonal lower lobe atelectasis at autopsy. This case is unusual because the lone nest of tumor cells was located in a very small perivascular scar in a lung essentially free from evidence of other disease. Furthermore, this solitary tumor focus was situated at a considerable distance from either bronchi or bronchioles and was immediately adjacent to the thickened pleural surface. Case 4, who died from the complications of carcinoma of the cervix, disclosed a small fibrotic area with some calcification at the apex of the left lung. Directly beneath this probable focus of tuberculosis, multiple tumor nests in a dense connective tissue stroma, and occasional intrabronchiolar masses were noted. Some atelectasis, emphysema, and deposition of anthracotic pigment was located near by. Case 8, dying in congestive heart failure, showed bilateral bronchopneumonia at autopsy. The one section in which tumor was accidentally discovered showed several intrabronchiolar polypoid lesions and one fibrotic zone with multiple discrete tumor acini. This area was not adjacent to the pneumonic process, and its relation to the pleura could not be determined.

Although it was not possible by means of the serial section technique to trace any direct continuity between the intrabronchiolar tumor and that noted within the scarred foci, this method of study did afford some idea of the relative size of these tumors. Blocks were selected which contained the largest areas of tumor, and were sectioned according to the method described above.

Since the neoplastic foci when so studied were consistently over 0.1 cm. in length from the site where the sectioning was begun, it is reasonable to assume that there was at least a similar amount of tumor proximal to the point where the growth was originally identified. The results of this investigation indicate that the tumor may measure somewhat over 0.2 cm. in at least one plane.

DISCUSSION

In discussing the etiologic agents which may be concerned with the production of primary lung carcinoma, Weller[7] mentioned the possible role of chronic inflammatory conditions which are accompanied by metaplasia and excessive regeneration. He stated that such conditions as bronchiectasis and chronic fibroid pneumonia might be predisposing factors, but that influenza, which some considered a causal agent, was of significance only by virtue of the chronic inflammation associated with its sequence. Wolbach and Frothingham,[8] in their report of the fatal cases in the influenzal epidemic at Camp Devens in 1918, noted evidence of repair of the bronchitis and peribronchitis as early as twelve or thirteen days after the onset of the disease. The small bronchioles had a fresh epithelium covering the underlying new connective tissue and the bronchioles appeared permanently enlarged. The authors' photomicrographs showing excessive regeneration of the epithelium in atelectatic alveoli which were undergoing repair in no way resemble the process noted in our eight cases. Pulmonary epithelial proliferation has been experimentally produced by Winternitz and associates[9] using intrabronchial insufflation of dilute hydrochloric acid. Overproduction of the epithelium occurred with the formation of polypi within the bronchioles, and extension of the epithelium into the surrounding tissue was described. Regenerating cells were identified by their size, cytoplasmic homogeneity, variation in nuclear density, and by the frequency of mitotic figures. The photomicrographs of these pathologic processes show no similarity to the changes we have described and the pictures of "extra bronchiolar invasion" are not convincing. In this connection it may be pertinent to mention an unusual case of chronic pneumonitis in an elderly woman which we recently encountered in our autopsy material. Microscopically, the pulmonary tissue showed extensive squamous metaplasia within the bronchioles and multicentric areas of invasion of surrounding alveolar spaces with epithelial atypism. Whether this case represents true metaplasia or early multicentric squamous carcinoma is not entirely clear, but it fails to show any histologic resemblance to the twenty cases of minute pulmonary neoplasm herein reviewed.

The frequency with which bronchiectasis has been noted as a concomitant pathologic finding is of considerable interest. This condition was present in four of our cases, in three of the five instances reported by Petersen and co-workers,[5] and in the single cases of Stewart and Allison,[4] and of Karsner and Saphir.[3] Furthermore, Womack and Graham[1] admit that the series of nine cases of cystic disease of the lung in which three "epithelial overgrowths" were present may be considered by some actually to be bronchiectasis. They classified their cases as congenital cystic disease because they felt there was evidence of developmental malformation of the lungs. These three cases would raise the incidence

of bronchiectasis to fourteen of a total of twenty recorded cases. Because of this association, we reviewed a large number of our autopsy and surgical specimens in an attempt to find additional examples of this unusual tumor, but none were found. Furthermore, Watts and McDonald,[10] in a thorough study of the pulmonary alveolar lining of fifty human lungs removed for bronchiectasis, did not encounter epithelial proliferation of the variety described herein. Although the relationship of bronchiectasis to these tumors is at present obscure, if this condition is a factor in the pathogenesis of these tumors, certainly one should expect a rising incidence of this neoplasm in view of the increasing number of cases coming to surgery.

The most important single consideration relative to these tumors is whether or not they represent a malignant growth. The pathologist's interpretation may afford a very serious prognosis in individuals of a young age group as in Cases 6 and 7 of the present series, both being originally reported as "incidental" oat-cell carcinomas. As we have stated above, our studies have convinced us of the relative benignancy of this neoplasm—a viewpoint not in accord with most other observers. To evaluate these tumors in relation to bronchogenic carcinoma a series of thirty-nine autopsied cases of bronchogenic carcinoma were studied as a small control group. It was felt that were these minute lesions incipient bronchogenic carcinomas, they should follow the same trends as to age and sex distribution, location, microscopic appearance, and metastatic tendencies. The following is a brief summary of this survey.

AGE

The average age of 57 years for the minute tumor group corresponded exactly with that of the bronchogenic carcinoma group. The occurrence of 20 per cent of the cases of the minute lesions below the age of 40 years is perhaps a little unusual for bronchogenic carcinoma of the usual type, but one cannot deny that incipient carcinoma might be present for some years before clinically recognized tumor results.

SEX

Fourteen of the nineteen (70 per cent) minute tumors where the sex data were available were females. This figure contrasts sharply with a 13 per cent female incidence in the bronchogenic carcinoma series. This finding casts grave doubts on the assumption that these tumors are bronchogenic carcinoma even in the early stage.

LOCATION

The minute lesions were consistently found in the extreme periphery of the lungs, and were apparently related to bronchioles. In contrast, the bronchogenic carcinomas, with the exception of adenocarcinomas which are frequently peripheral, were primarily related to large bronchi and were situated at or near the hilar region of the lungs.

MICROSCOPIC FEATURES

The minute tumors in our eight cases were characterized by relative regularity of the nuclei and lack of mitotic figures. Definite origin from bron-

chiolar epithelium could not be demonstrated. The microscopic features of manifest bronchogenic carcinoma must be separated according to cell types. Squamous carcinoma need not be considered since there is no histologic resemblance between these two lesions. Adenocarcinomas may likewise be discarded on this basis although their peripheral location suggests some similarity. Histologically, the so-called oat-cell, undifferentiated, or spindle-cell carcinoma of the lung most closely resembles these minute tumors. Study of the oat-cell carcinomas reveals a larger cell characterized by frequent mitoses, hyperchromatic nuclei with clumping of the chromatin, and nuclear necrobiotic and pyknotic changes (Fig. 7).

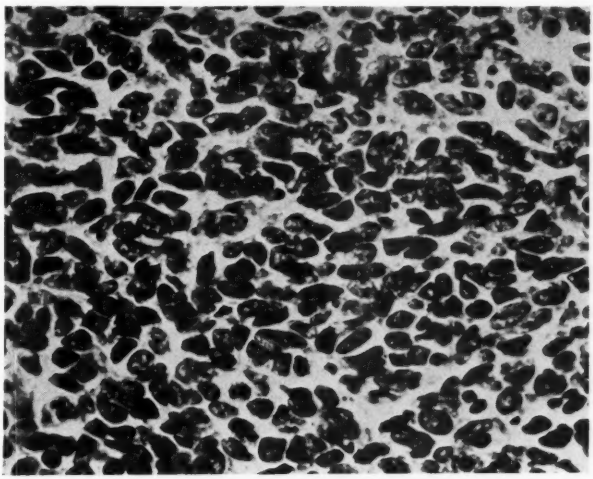

Fig. 7.—Oat-cell carcinoma for comparison with Fig. 3. The large cells show considerable pleomorphism, mitotic activity, and necrotic foci. (×650.)

METASTASES

Metastatic tumor was found in one of the twenty cases of these minute tumors. Since in only two of our eight cases were the lymph nodes studied, these negative findings do little to clarify the ability of these minute tumors to metastasize.

From the onset of this study we have been impressed by the striking resemblance of these minute neoplasms to the carcinoid type of intestinal tumor (Fig. 8). This analogy becomes increasingly attractive by reason of the fact that the carcinoid pattern is not only the most frequently encountered variety of bronchial adenoma, but also is considered to manifest the lowest degree of invasiveness.[11] Common features to both the carcinoid tumors and the minute neoplasms herein reported are sharply circumscribed nests of uniform epithelial cells lacking evidence of mitoses, nuclear hyperchromatism, and necrobiosis. In addition the pseudolymphatic spaces and capillary stalks within the cell nests

are frequently noted in carcinoid tumors elsewhere. Certain clinical characteristics of these minute pulmonary tumors such as their overwhelming preponderance of women (fourteen of the nineteen cases where these data are available) are much more suggestive of bronchial adenoma than bronchogenic carcinoma. The presence of several nests of tumor cells in a hilar node of one case does not invalidate the analogy since the extremely low grade of malignancy of the bronchial adenoma is well recognized. The argyrophile reaction was used on the two largest of these minute tumors with negative results, but it must be pointed out that true bronchial adenomas of the carcinoid type are rarely argyrophilic.[12] While we cannot state that these small peripheral tumors

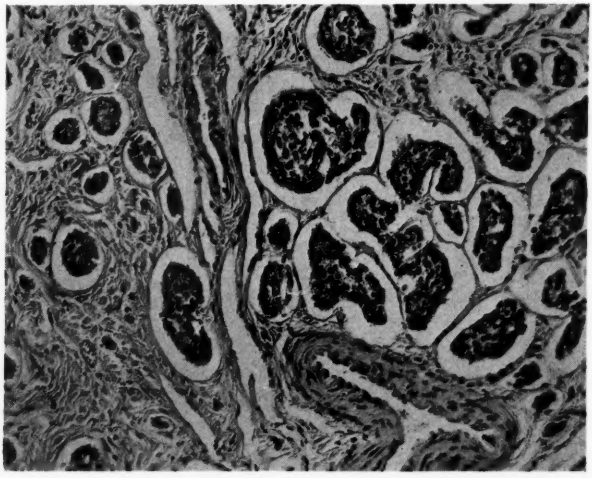

Fig. 8.—Intestinal carcinoid demonstrating the tendency of the cell nests to occur within spaces similar to the tumors herein reported. (×165.)

are identical with the large bronchial adenomas, we feel that their similarity in histologic pattern and in behavior to the carcinoid variety of adenoma is too great to be ignored (Fig. 9).

Since both the medical literature and the material in our files fail to indicate that one finds large tumors in the peripheral pulmonary fields corresponding in incidence, sex distribution, location, and cytologic structure to these minute tumors, one must assume that these relatively benign tumors remain small over a long period of time. Follow-up studies are largely precluded because the majority of the twenty reported cases have been incidental autopsy findings. Stewart and Allison[4] described a focus of tumor, identical in structure with those in our series, in a 32-year-old woman who underwent a lobectomy for bronchiectasis of long duration. The tumor which was accidentally discovered upon microscopic examination of the surgical specimen measured 0.1 cm. by 0.04 cm., and was located 0.5 cm. from the lateral surface of the lung. The authors considered this tumor to be an oat-cell carcinoma but were impressed by its close resemblance in many ways to basal cell carcinoma as seen in the

skin. In a recent communication Stewart[13] has informed us that this patient is well at present and free from any evidence of metastasis, now over nine years since the date of surgery. An attempt is being made at present to secure follow-up data on the three cases occurring in young individuals reported by Womack and Graham.[14] Cases 6 and 7 of our series who underwent pneumonectomy and lobectomy, respectively, for bronchiectasis, are now alive and well although it is slightly over one year in each instance since the time of surgery.

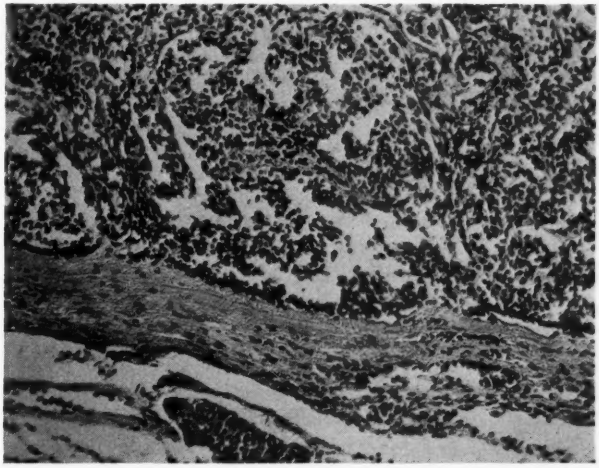

Fig. 9.—Large bronchial adenoma of the carcinoid type showing local invasiveness and a cellular pattern similar to the minute neoplasms herein described. (×170.)

SUMMARY

Eight new cases of an unusual type of minute pulmonary neoplasm have been analyzed in respect to their clinical and pathological features. Evidence is presented to show that these tumors are relatively benign in nature, resembling most closely the pattern seen in the carcinoid type of bronchial adenoma. In addition to their histologic structure, other common features of these tumors were their minute size, accidental microscopic discovery, subpleural location, and overwhelming predilection for females. The concomitant occurrence of bronchiectasis in the majority of the recorded cases suggests that this condition may be a factor in the pathogenesis of this atypical type of epithelial cell proliferation.

The authors wish to express their appreciation to Dr. Walter F. Bugden for permission to report Cases 6 and 7 of this series, and also to Mr. Louis Giorgianna of the Department of Photography for the illustrative material herein reproduced.

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TRANSPLEURAL BRONCHOTOMY

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TRANSPLEURAL bronchotomy is the operation of incising or resecting portions of the bronchial walls after making that surgical approach usually used for lobectomy, pneumonectomy, or exploratory thoracotomy. The approach to the pulmonary hilum may be posterolateral,[1-3] or anterolateral.[4, 5] In certain instances the purpose of the operation is to remove by local excision, benign, potentially, or semimalignant bronchial tumors usually of a polypoid nature.[1, 3, 5, 6] In other cases it may be utilized as a bronchoplasty for the relief of bronchial stenosis whether of tuberculous[7] or neoplastic origin. Third, it may be used as a part of exploratory thoracotomy to assist in obtaining tissue for frozen section, or in directly visualizing a tumor especially in the diagnosis of those small malignant bronchial and alveolar tumors whose shadows are likely to be discovered for the first time in roentgenogram surveys.

Reports of bronchoplasty for tuberculous stenosis have been made by Gebauer,[7] but only a few recorded operations have been performed for tumor.[1-3] It is the purpose of this paper to report experiences with five transpleural bronchotomies which were attempted for local excision of tumors of the adenomatous group (Table I).

In Table I are summarized some pertinent data of the results of bronchotomy. To appreciate the surgical problem encountered, a summation of each case is in order.

CASE REPORTS

CASE 1.—A. B., U.C.H. This operation was started with the idea of performing a left pneumonectomy through a posterolateral incision, since preoperative bronchoscopic removals over a period of six years had shown the recurrent adenoma to be located in the left-stem bronchus. Bronchiectasis was severe in the lower lobe. After freeing numerous dense adhesions from the left lower lobe, the patient's condition was deteriorating, so that it appeared wise to terminate the operation without removal of the upper lobe. After amputating the left lower lobe below the upper lobe take-off, the tumor in the left-stem bronchial wall was totally excised (Fig. 1). The edges of the bronchotomy wound were closed with interrupted fine silk. Postoperative course was smooth. Closed tube drainage of the pleural cavity was established at operation but very little air escaped. The tube was removed on the second postoperative day. Follow-up five years since bronchotomy with left lower lobectomy shows that the patient is well, free of signs of recurrence and suppurative symptoms, despite some bronchiectasis having been proved in the left upper lobe before surgery. (An illustration of the surgical technique used in this case has been previously reported.[8])

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Read (by title) at the Thirty-first Annual Meeting of The American Association for Thoracic Surgery, Atlantic City, New Jersey, April 16-18, 1951.

CASE 2.—E. S., C.L.H. This operation was begun as a transpleural bronchotomy through an anterolateral approach. It was expected from the preoperative bronchoscopic studies which had been carried out for treatment of this cylindromatous adenoma for six years before transpleural bronchotomy, that a condition similar to that of Case 1 (Fig. 1) would be found, but instead widespread pleural and mediastinal metastases were discovered. Since both right- and left-stem bronchial walls as well as the carina were extensively infiltrated, complete excision of the tumor for relief of bronchial obstruction was out of the question. The asphyxial symptoms might be relieved by a bronchoplasty, and this was done by incising completely the lower anterolateral wall of the trachea and left-stem bronchus in a longitudinal direction for a distance of 2.5 cm. and suturing with fine silk the cut edges in a horizontal plane so as to widen the orifices of the left-stem bronchus and lower end of the trachea. From this point, until closure of the bronchoplasty was complete, anesthetic oxygenation was carried on through a 22F uretheral catheter inserted into the right-stem bronchus transpleurally. The bronchial incision extended through malignant neoplastic tissue. Closed tube drainage of the pleural cavity was established, but prac-

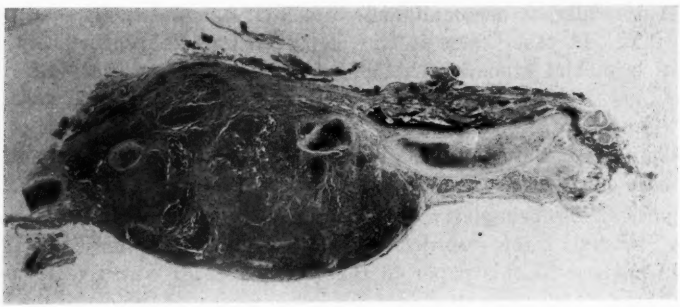


Fig. 1.—Case 1. A.B., U.C.H., woman, aged 38 years, S.P. 46-589. Low-power magnification of surgical specimen of recurrent carcinoid bronchial adenoma removed at bronchotomy. Note that five bronchial cartilages are included in the specimen. The specimen was 3.5 cm. by 1.0 cm. by 1.0 cm.

TABLE I

	CASE	YEAR	SEX	AGE	DIAGNOSIS	RESULT OF BRONCHOTOMY	FOLLOW-UP
1	A. B.	1946	female	38	Carcinoid adenoma. Recurrent after bronchoscopic treatment.	Tumor removed with bronchial wall from left stem, 4 cartilages. Left lower lobectomy	Living and well. Five years no recurrence.
2	E. S.	1947	male	58	Recurrent cylindromatous adenoma with widespread metastasis.	Unable to remove tumor. Bronchoplasty for asphyxia left stem and trachea.	Died 2 months P. O. Metastasis and asphyxia.
3	D. P.	1949	female	14	Serous glandular adenoma.	Tumor removed left stem. Base cauterized, direct vision.	Living and well 2 years. No recurrence.
4	S. S.	1949	female	45	Carcinoid adenoma. Recurrent after bronchoscopic treatment.	Tumor removed right stem. Two cartilages.	Living and well, 18 months.
5	B. P.	1949	male	26	Carcinoid adenoma. Bronchoscopic treatment attempted but failed.	Unable to remove tumor of left lower lobe. Invaded left upper lobe bronchus. Left pneumonectomy.	Living and well, 2 years.

tically no air escaped, and the tube was removed on the third day. Although the patient obtained partial relief from dyspnea and was able to leave the hospital on the twelfth postoperative day, two months later he succumbed shortly after readmission from asphyxial symptoms. Post-mortem examination disclosed the widespread infiltration of the bronchial and adjacent tracheal walls. Surprisingly, the suture line of the bronchoplasty was well healed. The pathologic findings in this case have been reported previously in the JOURNAL OF THORACIC SURGERY.[8]

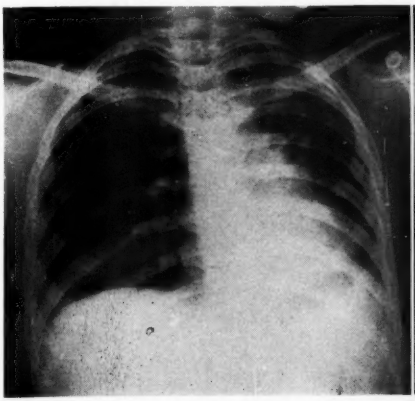


Fig. 2.

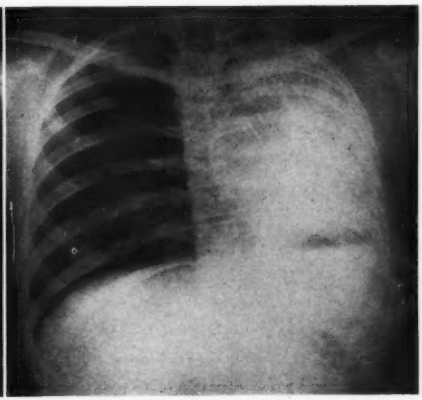


Fig. 3.

Fig. 2.—Case 3. D.P., H.G.H., girl, aged 14 years, Feb. 28, 1949. Roentgenogram of the chest showing abnormalities of the left hilar region at a time when wheezing was prominent and "asthma" was the diagnosis. Left lower lobe atelectasis probably present.

Fig. 3.—Case 3. D.P., H.G.H., girl, aged 14 years, April 15, 1949. Roentgenogram of the chest showing complete atelectasis of left lung.

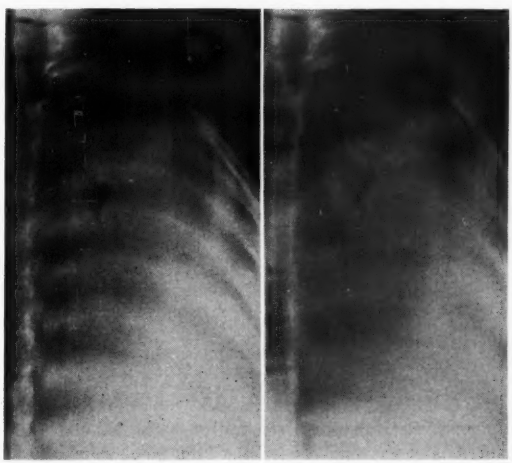


Fig. 4.—Case 3. D.P., H.G.H., girl, aged 14 years, April 16, 1949. Planigram levels 3 and 4 showing complete occlusion of left-stem bronchus from tumor mass extending to carina.

CASE 3.—D. P., H.G.H. From the preoperative radiologic study (Figs. 2, 3, and 4), bronchoscopic findings, and the histologic evaluation of the biopsy, it was felt that a large polypoid tumor belonging to the adenomatous group was obstructing completely the left-stem bronchus, and, although wheezing had been present for more than a year, complete bronchial occlusion was only about one week's duration. It was believed that pulmonary suppuration would not ensue postoperatively if local excision could be utilized without producing bronchial stenosis. Accordingly, a transpleural bronchotomy was performed April 20, 1949, through a posterolateral incision. The left lung was airless and heavy. The posterolateral aspect of the left-stem bronchus and lower trachea were easily exposed below the arch of the aorta. The tumor could be palpated through the bulging bronchial tube, but nowhere was there a visible or palpable sign of the tumor infiltrating beyond the bronchial wall. Adjacent lymph nodes were innocent in gross appearance and frozen sections. The bronchotomy incision extended three centimeters longitudinally from the lower end of the trachea to the take-off of the superior segmental bronchial orifice of the lower lobe. Although most of the incision was through the soft muscular wall of the left-stem

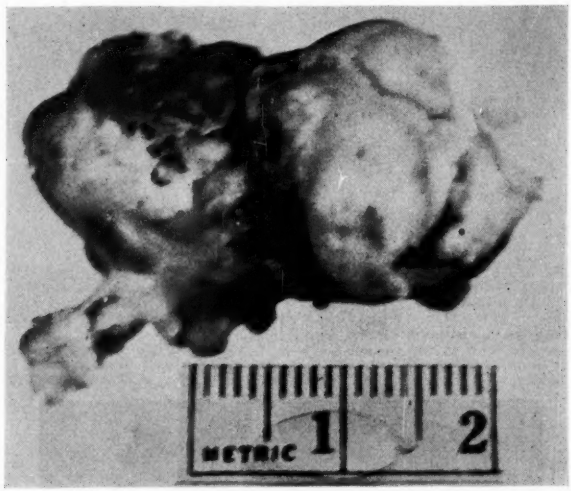


Fig. 5.—Case 3. D.P., H.G. H., S.S. 516-49. Gross surgical specimen removed from left-stem bronchus in toto via transpleural bronchotomy. Note cystic structures and stalk.

bronchus, it was not possible to avoid cutting some cartilaginous rings. The large cystic polypoid tumor (Figs. 5, 6, and 7) mushroomed out of the bronchotomy opening into the pleural cavity so that with gentle traction on the tumor the mesial wall and point of attachment by a stalk 0.5 cm. in diameter could be thoroughly examined. This examination of the interior of the stem bronchus was made easier by the aspiration from the lower lobe and main bronchus of some 30 c.c. of slightly turbid damned-up fluid, more serous than mucous. Careful palpation of the mediastinal outside surface of the mesial wall and subcarinal area failed to disclose any evidence of invasion beyond the cartilages at the point of attachment. Therefore, the stalk was amputated flush with the internal surface of the cartilages including a 2 to 3 mm. rim of bronchial mucosa. Small pieces of adjacent bronchial mucosa were also taken for histological examination. The 1.0 cm. crater left denuded of mucosa was now superficially cauterized with the high frequency endotherm cautery. The bronchotomy incision was closed with one layer of interrupted fine silk; no attempt to reinforce the suture line with mediastinal pleura was made. The anesthetist expanded the

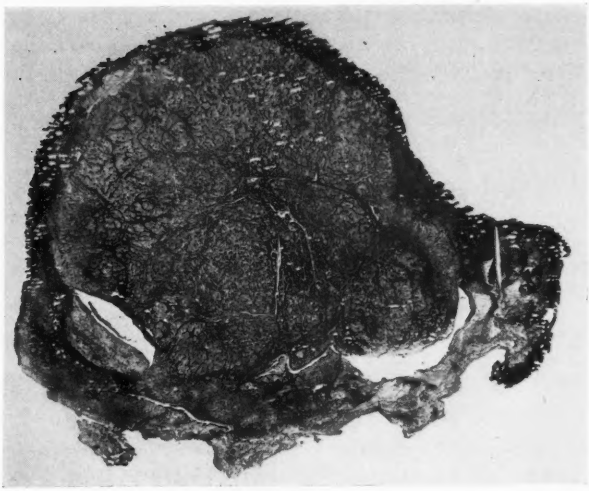


Fig. 6.—Case 3. D.P., H.G.H., S.S. 516-49. Cross section at right angles to long axis of tumor seen in Fig. 5. Low power. Note glandular structure and systic areas and bronchial mucosa covering endobronchial surface of tumor.

Fig. 7.—Case 3. D.P., H.G.H., S.S. 516-49. High-power view showing glandular structure, numerous delicate connective tissue septa, and clear cell. Tumor probably arose from serous mucous bronchial glands.

lung with some difficulty but no leakage of the bronchotomy opening was observed. Closed tube drainage of the pleural cavity was established. Only a small amount of air escaped through the tube the first day. The tube was removed on the second day.

Re-expansion of the lung was carefully observed with frequent roentgenograms of the chest. Almost complete atelectasis was observed the first two days (Fig. 8). Tracheal aspiration appeared to aid the re-expansion and thoracentesis was necessary. By the third day, only a small amount of fluid remained and the upper lobe was almost completely expanded (Fig. 9). In order to observe the configuration of the bronchi, bronchograms were done one month (Figs. 10*A* and 10*B*) and fourteen months postoperatively (Figs. 11*A* and 11*B*). One month postoperatively, clubbed shaped bronchial dilatations were delineated in the superior segment of the left lower lobe, and cylindrical dilatations in other segments, although at this time the patient had no cough or sputum. One year and two months postoperatively (Figs. 11*A* and 11*B*) the bronchograms fail to delineate any club-shaped bronchiectasis in the superior segment of the left lower lobe and the cylindrical dilatations are also less marked, but are present. She had no febrile episodes during this time, and

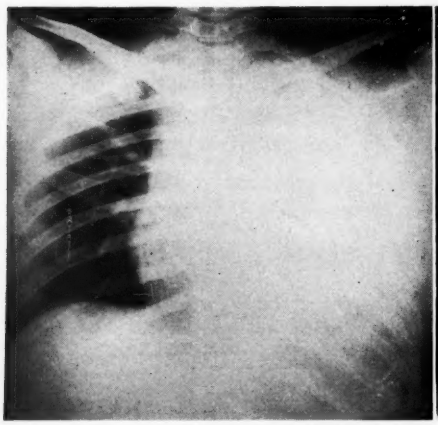


Fig. 8.

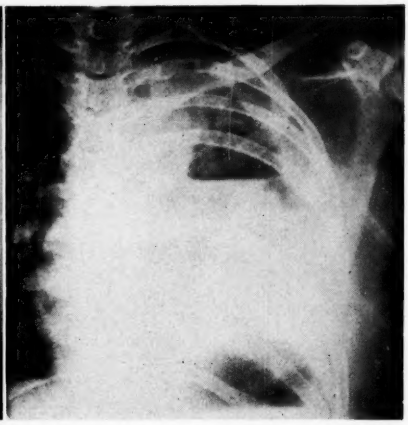


Fig. 9.

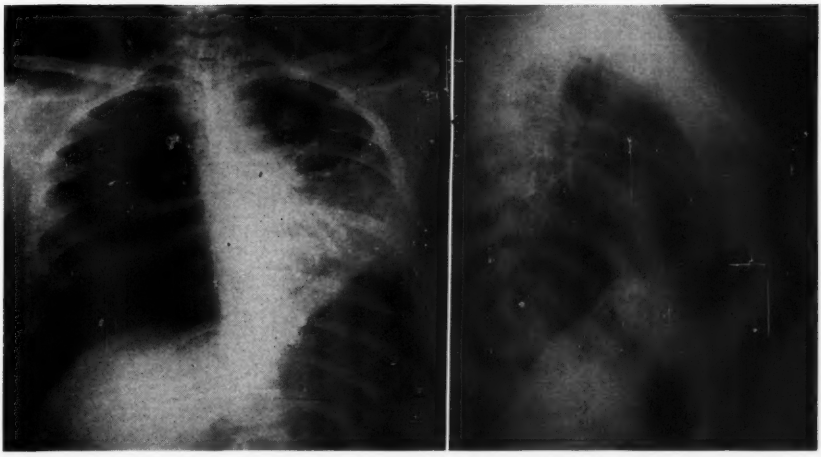
Fig. 8.—Case 3. D.P., H.G.H., April 22, 1949. Second day postoperative transpleural bronchotomy. Roentgenogram of the chest showing pleural fluid and atelectasis of the left lung.

Fig. 9.—Case 3. D.P., H.G.H., April 23, 1949. Third day postoperative transpleural bronchotomy. Roentgenogram of chest showing marked clearing of atelectasis and fluid; compare with Fig. 8.

has missed no time from school. Bronchoscopic examination eighteen months after transpleural bronchotomy shows a normal lumen to the stem bronchus, some black silk is seen covered by transparent mucosa: no signs of suppuration. She has remained well for two years with no sign of recurrence.

The bronchogram studies one year apart (Figs. 10*A* and *B* and 11*A* and *B*) are significant because they, as well as the bronchoscopic examinations, demonstrate that bronchial stenosis does not result after transpleural bronchotomy with removal and direct cauterization of the base of a polypoid tumor of this type. A cure can be expected because no neoplastic tissue was seen in the biopsies of the mucosa surrounding the base, and because there has been no sign of recurrence for more than two years. Nevertheless, annual bronchoscopic examinations have been advised.

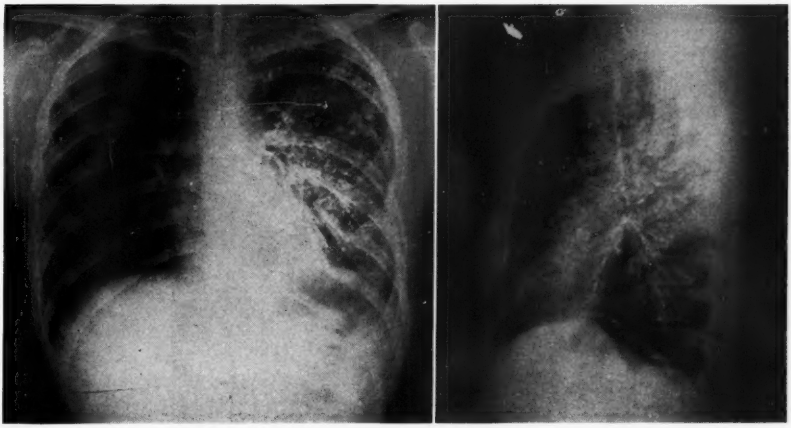
CASE 4.—S. S., C.L.H., presented a problem similar to that of Case 1. In a woman of 45 years, a carcinoid adenomatous polypoid tumor had recurred five years after the entire tumor was thought to have been removed bronchoscopically. Roentgenologic and bron-



A. *B.*

Fig. 10*A*.—Case 3. D.P., H.G.H., May 16, 1949. Bronchogram one month after transpleural bronchotomy. Posteroanterior view showing club-shaped dilatations in the superior segment of the left lower lobe and cylindrical bronchiectasis in other segments of the left lower lobe.

Fig. 10*B*.—Case 3. D.P., H.G.H., May 16, 1949. Bronchogram one month after transpleural bronchotomy. Left lateral view showing puddling of lipiodol in the superior segment of left lower lobe.

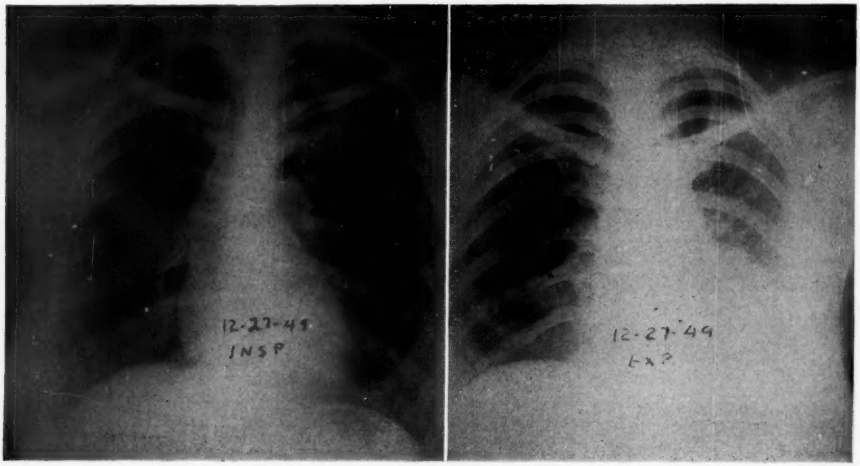


A. *B.*

Fig. 11*A*.—Case 3. D.P., H.G.H., June 15, 1950. Bronchogram one year and two months after transpleural bronchotomy. Compare with Fig. 10*A*. Posteroanterior view showing failure to delineate club-shaped bronchiectasis seen one year before, and less cylindrical dilatation in other segments. Patient is symptom free.

Fig. 11*B*.—Case 3. D.P., H.G.H., June 15, 1950. Bronchogram one year and two months after transpleural bronchotomy. Compare with Fig. 10*B*. Left lateral view. Note again failure to delineate club-shaped bronchiectasis in superior segment of left lower lobe. Compared to Figs. 10*A* and 10*B*, Figs. 11*A* and 11*B* demonstrate a diminuation in the bronchiectasis following transpleural bronchotomy.

choscopic examinations disclosed that complete obstruction of the right-stem bronchus from this tumor was of only a few days' duration, and, as in the previous case, was associated with taking of bronchoscopic biopsy. In this instance, especially, we were able to observe radiologically the transformation of a right lung with tension emphysema (Figs. 12*A* and 12*B*) into a completely obstructed lung (Figs. 13 and 14). Since this woman had no previous suppurative symptoms, we felt justified to attempt to conserve her lung by performing on Dec. 30, 1949, local excision through transpleural bronchotomy via an anterolateral approach



A. *B.*

Fig 12*A* and *B*.—Case 4. S.S., C.L.H., woman, aged 45 years, Dec. 27, 1949. Inspiration and expiration roentgenograms of chest showing shift of mediastinum to contralateral left side and Recurrent carcinoid bronchial adenoma right-stem bronchus, with tension emphysema of the Note, also, tracheal mediastinal displacement and opacity of the homologous right lung.

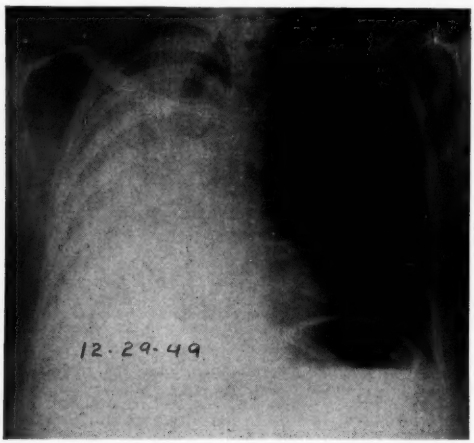


Fig. 13.—Case 4. S.S., C.L.H., Dec. 29, 1949. Twenty-four hours after bronchoscopy. Posteroanterior view roentgenogram of the chest showing complete obstruction and atelectasis of the right lung with mediastinum shifted to the homologous side. Compare with Figs. 12 and 14.

in the third interspace. After entering the pleural cavity, the right lung was found to be heavy and airless. The right-stem bronchus was readily exposed after elevating the lung from its posterior bed and displacing the upper lobe downward. It was difficult to feel the tumor through the bronchial wall, and, as in the previous case, neither mediastinal extension nor adjacent involved lymph nodes were found in frozen sections. The right lung was now replaced in its posterior bed and vena azygos, superior pulmonary vein, and upper-lobe branch of the right pulmonary artery were retracted in order to expose the lower end of the trachea, right upper-lobe bronchus, and anteromedial surface of the right-stem bronchus.

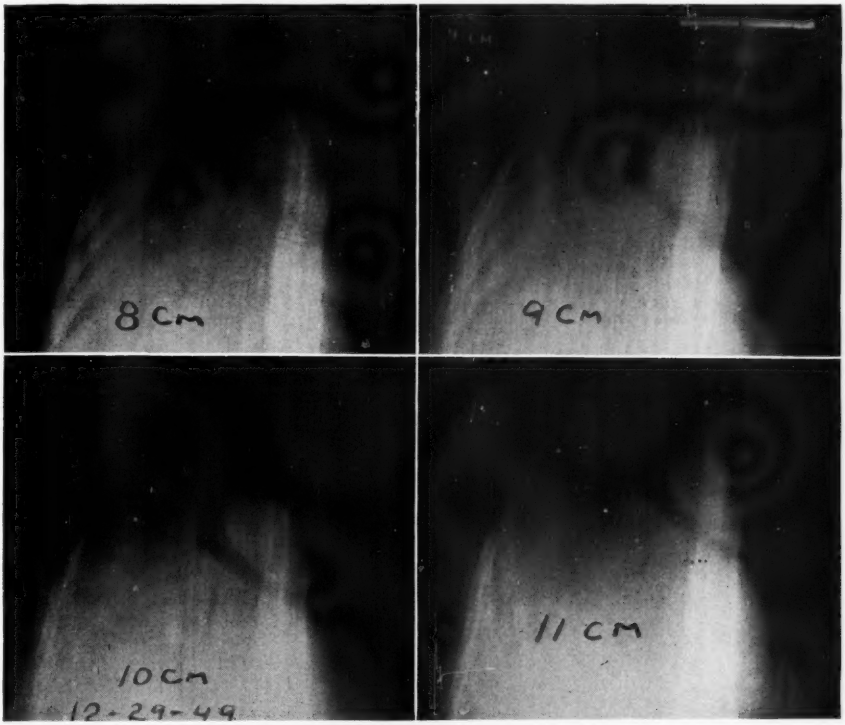


Fig. 14.—Case 4. S.S., C.L.H., Dec. 29, 1949. Planigrams levels 8, 9, 10, and 11, showing the complete obstruction of the right-stem bronchus at the level of the carcina by neoplasm. Note, also, tracheal mediastinal displacement and opacity of the homologous right lung.

An incision was made through the bronchial wall between the cartilages of the anteromesial surface of the bronchus from the orifice of the upper-lobe bronchus to the mediastinal border of the subcarinal surface of the right-stem bronchus. Through this bronchotomy the interior of the right-stem bronchus was explored and found to contain a fleshy friable polypoid tumor which was attached to the mesial wall of the right-stem bronchus (Fig. 15). The attachment was sessile and covered an area of approximately one square centimeter. This sessile base involved two large cartilaginous rings (Figs. 15 and 16) which were resected with the tumor. Again bronchial fluid, about 20 c.c. slightly purulent, was encountered. In order to excise the tumor with the bronchial wall (Fig. 17) the bronchotomy incision was continued to completely encircle its sessile attachment. The cartilages were portions of the first and second rings below the carinal cartilage. Closure of this defect

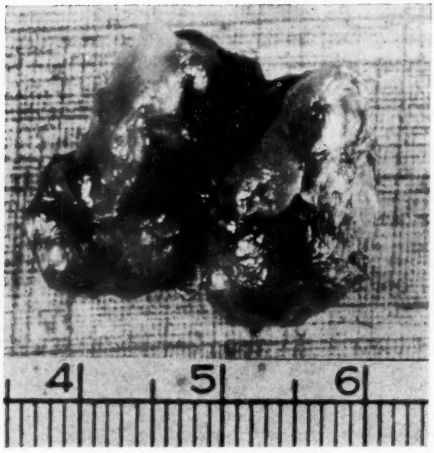


Fig. 15.—Case 4. S.S., C.L.H. Gross surgical specimen of recurrent carcinoid adenoma removed from right-stem bronchus by transpleural bronchotomy.

Fig. 16.—Case 4. S.S., C.L.H. Low-power view of cross section of recurrent adenoma shown in Fig. 15. Note the cartilages and bronchial wall resected intact with the endobronchial tumor. See Fig. 17 for high-power of invasive tumor nodule.

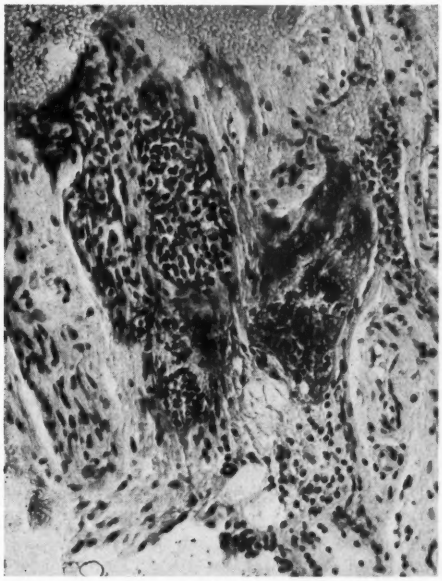


Fig. 17.—Case 4. S.S., C.L.H. High-power view of area beyond the cartilages marked by squares in Fig. 16 showing nodule of adenoma beyond the reach of the bronchoscope. Such nodules probably account for recurrences after bronchoscopic removal.

Fig. 18.—Case 5. S.S., C.L.H., April 10, 1950. Roentgenograms of the chest showing slight blunting of the right costophrenic sinus. Satisfactory aeration of right lung three months after transpleural bronchotomy and resection of recurrent bronchial adenoma. Sixteen months after that operation the patient was well, with no signs of recurrence.

was difficult but was managed by displacing the carinal cartilage downward with traction sutures of medium silk that were removed after tying coapting fine silk interrupted sutures. No attempt to cover the defect with pleura was made. Closed tube pleural drainage was established. Postoperatively, there was little leakage of air and the tube was removed on the third day. Expansion of the right lung was satisfactory except for one area of segmental atelectasis. She was discharged on the tenth postoperative day, breathing without wheezing and dyspnea for the first time in months. Three months later a roentgenogram of the chest showed satisfactory aeration of the right lung (Fig. 18) with disappearance of the segmental atelectasis. She has continued work as a saleslady uninterrupted during the past fifteen months. Radiologic examination sixteen months postoperatively discloses essentially the same appearance as in Fig. 18.

CASE 5.—B. P., C.L.H. This white man 26 years of age had had symptoms of mild pulmonary suppuration for more than five years before hemoptysis occurred. Attempts at bronchoscopic removal of a carcinoid adenoma of the left lower lobe failed because of excessive hemorrhage and large size. It was felt that transpleural operation was indicated, and that the operation should be planned so that local excision might be done if the preoperative evaluation proved accurate, i.e., if the tumor had not become too large, was still located in a suitable position where repair of the bronchotomy could be achieved without obstructing segmental orifices; if no metastases were found; if no evidence of irreversible suppuration of the left lower lobe existed; and if the upper-lobe bronchus were not involved. At operation, which was performed through a left posterolateral incision, bronchotomy of the posterior wall of the left lower lobe disclosed an endobronchial portion of the tumor which at first appeared to be amenable to local excision or lobectomy. However, exploration of the mediastinal area about the distal end of the left-stem bronchus demonstrated the iceberglike nature of the tumor, and that the extrabronchial portion invaded from the mediastinal side the wall of the left upper-lobe bronchus. Therefore, a left pneumonectomy was performed. Postoperative convalescense was smooth. Two years postoperatively, a recent examination disclosed him to be well and without evidence of any recurrence.

DISCUSSION

The experiences described support Eloesser's[1] contentions made in 1940 that transpleural bronchotomy is a feasible conservative method of removing certain "benign" tumors of the bronchus which by reason of their anatomic situations or their doubtful extensions are not amenable to safe and certain bronchoscopic removal. Since 1940, the unpredictable potentially malignant nature of the adenomatous bronchial tumors has been thoroughly proved.[8-18] In spite of this malignant potentiality, slow growth, tendency for encapsulation, and high capacity for being limited by normal tissue environment, such as bronchial mucosa, cartilages and lung parenchyma, make many of the adenomatous bronchial tumors amenable to complete local excision. Furthermore, it appears entirely possible to differentiate those tumors which are amenable to complete local excision via transpleural bronchotomy by the aid of clinical studies before operation[10-13] and by further information obtained at the time of operation. This observer emphatically advises against bronchotomy in every case of adenomatous bronchial tumor, and, of his forty cases, this paper contains the sum total of his experiences with bronchotomy in this type of neoplasm. But, our past knowledge is based on adenomas that were of long duration often accompanied by regional lymph node metastases, marked pneumonitis, bronchiectasis, abscess, and pleuritis, where pulmonary resection must

be done to eradicate suppuration as well as tumor. Twenty-three of the forty patients have had pulmonary resection.[14] Such polypoid neoplasms discovered early, as in the wheezing stage (Case 3, D. P.) probably will not yet have metastasized nor have serious suppurative sequelae, and so will lend themselves to transpleural bronchotomy. Although the endobronchial obstruction may be relieved via the bronchoscope, it has been necessary to perform transpleural surgical procedures more and more for bronchoscopic failures[15] and for late recurrences after apparent complete bronchoscopic removal (Case 1, A. B., and Case 4, S. S.). Complete local excision via the bronchoscope cannot be accomplished because of endomural (Fig. 17) and extrabronchial extensions of the tumors in approximately 90 per cent of the cases.[16]

Since the majority of these patients are below the age of 40 years,[17, 18] and conservation of lung can be compatible with complete local excision of the tumor by transpleural bronchotomy, this procedure should be considered in every case where the following conditions can be met:

1. A histologic diagnosis of a benign, semibenign, or potentially malignant tumor has been established whether before operation or by frozen section at the time of operation.

2. Malignant degeneration with metastases or widespread bronchial wall infiltration should not have occurred.

3. Irreversible or serious pulmonary suppuration is absent and the state of the distal lung is such that it will not become a hazard and will remain aerated postoperatively.

4. The tumor should be located in an accessible bronchus usually lobar, stem, or adjacent lower end of trachea.

5. Extensive extrabronchial growth and pressure necrosis should not have occurred, but the tumor should have demonstrated a tendency to remain localized.

6. Preferably, the tumor should have a stalklike bronchial attachment. Sessile attachments had best not involve more than two or three larger cartilaginous rings or four or five smaller rings.

7. The bronchial walls should be supple and amenable to suture without production of stenosis after local excision of the tumor.

8. If an adenomatous bronchial tumor is recurrent or bronchoscopically incompletely removed, it should be well confined and localized.

9. The state of the pleural cavity and hilum of the lung should be such as to lend itself to easy access to the large bronchi.

SUMMARY

Certain adenomatous localized benign, semi- or potentially malignant bronchial tumors have shown themselves amenable to complete local excision via transpleural bronchotomy. The surgical technique and experiences in five cases have been presented. Indications for this operation are discussed. There was no operative mortality. The results were eminently satisfactory in three cases. In one case, the result was poor (Case 2, E. S.) and done as an expedient

to relieve asphyxiating malignant obstruction. In the fifth case, the pneumonectomy was necessary because widespread bronchial infiltration had already occurred. Conservation of lung and complete local excision in the carefully selected case is stressed.

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THE NATURAL HISTORY OF SO-CALLED TUBERCULOMAS

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THE term "tuberculoma" of the lung is applied to solid caseous foci, representing undrained tuberculous abscesses filled with inspissated caseous material, from which tubercle bacilli can be recovered in large numbers. The term has also been applied on occasions to other pulmonary lesions.[1, 2]

Persons with such lesions complain mainly of feeling "under the weather" rather than of any specifically respiratory symptoms. Physical signs are absent, the sputum is negative, and the lesion is found only on radiologic examination, and is often detected more easily on screening than with a film, since it may be hidden behind a rib or the scapula. The lesion is roughly spherical in shape, from ½ to 3 cm. in diameter, with sharply defined borders, and fairly uniform density. Smaller daughter foci may be seen near to the parent focus. The diagnosis of a solid focus of tuberculous caseous material is often a presumptive one determined solely on interpretation of the radiologic appearances, and other conditions have to be considered such as primary and secondary neoplasms, cysts, abscesses, and encapsulated interlobar empyemas.

In view of the paucity of symptoms and the circumscribed appearance of the lesion, patients with "tuberculomas" are frequently kept under observation. In others, where a pneumothorax has been induced, the focus has been found unchanged when the lung has been allowed to re-expand. Now it is recommended that the proper treatment of such solid caseous foci is resection of the affected segment of the lung. Such treatment seems drastic if these lesions run a benign course and carry a favorable prognosis.

In an attempt to elucidate this problem, eighteen patients, with a total of twenty-three "tuberculomas," have been found who have been kept under observation. Two patients had two solid caseous foci in one lung, and another had three foci in one lung and one in the other lung. The course of these "tuberculomas" was as follows:

Calcified.—Four foci. Observed 15, 22, 54, and 148 months.

No change.—Seven foci. Observed 12, 12, 16, 24, 89, 89, and 89 months.

Enlarged.—Five foci. Observed 20, 22, 22, 24, and 50 months.

Cavitated.—Four foci. Observed 5, 23, 89, and 90 months.

Cavitated with Bronchogenic Spread.—Three foci. Observed 30, 38, and 51 months.

It appears from these figures that "tuberculomas" are relatively indolent lesions. Even when cavitation occurred, in four of seven cases bronchogenic

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dissemination of disease did not ensue. In only four, however, did definite healing occur, while in twelve the pathologic process continued.

SUMMARY

The results of observation of twenty-three so-called tuberculomas are reported. Altogether three cavitated with bronchogenic spread, four cavitated only, and five enlarged.

Thus resection of the affected segment of the lung, since it carries practically no mortality and does not entail the sacrifice of any appreciable amount of lung tissue, seems to be the treatment of choice for these solid lesions. Especially is this so when the difficulty in making a differential diagnosis from peripheral carcinoma is borne in mind. A correct diagnosis of carcinoma may only become evident at a stage when curative treatment for this condition has become impossible.

I wish to express my appreciation to Mr. F. Ronald Edwards for his interest, advice, and criticism.

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LOBECTOMY AND PNEUMONECTOMY IN TUBERCULOSIS

A Report of 54 Cases

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THE first tentative attempts at pulmonary resection in tuberculosis therapy were made in the last two decades of the nineteenth century. But it was not until the third and, in particular, the fourth decades of this century that improved diagnostic technique and chemotherapy permitted a more accurate evaluation of the problems involved in the treatment of pulmonary tuberculosis by resection of the affected tissue. As a natural consequence of the rapid progress of thoracic surgery, it is now possible to study the results in large series of tuberculous patients treated with this procedure. The foremost names in the Anglo-American literature are those of Overholt, Bailey, Sweet, etc. Among European writers, Klinkenberg has reported a large series of resection cases. The Swedish material hitherto published (Crafoord, Rudström, Wulff) was rather small and the observation period was relatively short.

The first of our patients has been observed for fifteen years, and during these years an increasing number of patients have been treated with resection. We consider, therefore, that the time is now opportune for reporting the results of treatment in fifty-four patients who underwent pulmonary resection at Sabbatsberg Hospital in Stockholm during the period 1935-1950.

To obtain a survey of the results in earlier studies, a table has been compiled showing findings from investigations made before the introduction of chemotherapy and from recently published papers concerning operations carried out with the protection of chemotherapy (para-aminosalicylic acid [PAS] and streptomycin). A number of data were obtained through personal communication with Dr. Swirenga (Holland).

No distinction has been made in the table between "good" and "poor" surgical risks. The mortality and complications rates were high in the early series, and were considerably reduced by the advent of chemotherapy. In addition to the beneficial action of the drugs, the patients in the later studies had the advantage of all the advances in surgical and anesthetic technique and post-operative therapy.

The patients who comprised the clinical material in this study all underwent operation at Sabbatsberg Hospital. Rather more than half of them (twenty-nine) received pre- and postoperative care at Söderby Hospital. The others were referred to Sabbatsberg by sanatorium physicians in the provinces. As the surgical procedures were throughout the responsibility of the same surgeon (Prof. C. Crafoord), a continuity was created which was important in the assess-

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ment and planning of the interventions. On the other hand, the preoperative and late postoperative treatment was inevitably subject to variations from the fact that the patients were hospitalized in different institutions.

The operative procedures were as follows: 18 lobectomies, 3 lobectomies combined with segmental resection, 1 segmental resection, and 32 pneumonectomies. The last-named included 7 cases of pleuro-pneumonectomy, an intervention which undoubtedly involves increased risk of hemorrhage and shock. The predominance of women (thirty-three) may possibly be ascribed to the higher incidence of bronchial tuberculosis in females.

TABLE I.

AUTHOR	NUMBER OF CASES		TOTAL DEATHS		POST-OPERATIVE MORTALITY		SPREADS	
	NO SPECIFIC CHEMO-THERAPY	SPECIFIC CHEMO-THERAPY	NUMBER	PER CENT	NUMBER	PER CENT	NUMBER	PER CENT
Overholt et al.	196		46	24	27	14	54	28
Sweet	63		28	44	9	16	20	32
Clagett et al.	29		4	14	2	7	8	28
Bailey et al.	100	100	37 16	37 16	27 16	27 16	15 1	15 1
Moore et al.		74	6	8	6	8	3	4
Day et al.	202		25	12	14	7	25	12
Himmelstein et al.	73		15	21	12	16		
Jones et al.	35	88	10 5	29 6	8 5	23 6	7 4	20 5
Munz et al.		53	4	8	4	8	1	2
Swierenga		227			9	4		

Those patients who received no specific chemotherapy (twenty-three in number) were for the most part operated on before 1948. The youngest of the series was 8 years old and the oldest 63 years of age. None of the patients had been observed for a shorter period than one year after the disease was diagnosed. The great majority had been followed for many years, and during that time had received sanatorium care when such was necessary. In the patients classed as having bilateral disease, the contralateral process was practically always estimated to be clinically inactive. No patient had permanent contralateral collapse, but two had earlier contralateral artificial pneumothorax. The number of pneumonectomies performed during the different periods of the investigation was: 1935-1942; six; 1943-1947, eight; 1948-1949, eight; and up to September, 1950, ten. Corresponding figures for lobectomies were: zero, five, nine and eight.

Throughout the two tables of indications distinction has been made between patients who had previously received active therapy either in the form of permanent collapse (thoracoplasty) or temporary collapse (pneumothorax or pneumoperitoneum with phrenic nerve interruption), and cases where resection was the first active measure. The indications for operation were not notably

divergent from those reported in the Swedish and foreign literature. Thus one group consisted of fourteen patients with residual cavities after thoracoplasty or revision thoracoplasty or with cavities so localized that collapse therapy was unlikely to be effective; these cavities were usually situated in the lower lobe. Another important indication was bronchostenosis secondary to tuberculosis with intermittent or constant retention symptoms and with positive sputum (seventeen patients). This group included some cases where the changes peripheral to the stenosis were so marked that the pulmonary parenchyma was more or less destroyed. A third group comprised 6 patients with bronchiectasis secondary to tuberculosis and persistent and positive sputum. Where sputum conversion can be obtained, these patients should be submitted to surgery on the same indications as for nontuberculous bronchiectasis. In 2 patients who underwent operation for nonspecific bronchiectasis, tuberculosis was revealed by microscopic examination. Those cases (seven in number) where earlier therapy had resulted in fistula formation and empyema presented great difficulties. Pleuro-pneumonectomy was found to be the only and final resort for such patients in our study. Extensive unilateral tuberculosis constituted the indication for surgery in five patients. The series also includes three cases of tuberculoma, two of which were thought to be tumors. More unique than the above-named common indications is a case of arteriobronchial fistula which has previously been described by Crafoord.

When judging the indications in all these patients, the appearance of the bronchial tree was considered to be as important as the extent of the parenchymatous lesions. No less than twenty-seven of the fifty-four patients were found to have definite bronchial tuberculosis. We have, however, always endeavored by local and general therapy to convert the bronchial lesions to inactivity before operation.

Prior to 1948 no patient had received specific chemotherapy. To begin with, chemotherapy was given only on special indications: preoperative chemotherapy was reserved for "poor risks" and postoperative for complications. Gradually, as the drugs became more easily procurable, a more methodic system of therapy was adopted. As far as possible PAS was given preoperatively (more recently some patients have received thiosemicarbazone), and streptomycin was reserved until the time of operation so as to avoid early development of bacillary resistance.

There was, however, a group of patients for whom the initial prospect was considered favorable for thoracoplasty but the course of events necessitated the use of intensive chemotherapy: in these patients resistance to streptomycin had developed before resection was performed. In a few cases of extensive disease, thorough medication with all available chemotherapeutics failed to make the patient fit for collapse therapy; primary resection was then carried out but bacillary resistance had already developed.

No uniform schedule of therapy can be given as the duration of treatment varied very widely in the different patients. Preoperative PAS medication up

to five and six months in length was not uncommon. Streptomycin was sometimes added in short courses of ten to fourteen days during PAS therapy. During the last year, streptomycin has always been given in combination with PAS so as to delay bacillary resistance. The usual dosage of PAS was 14 Gm. granulate (70 per cent PAS) daily in 4 divided doses. Streptomycin was given in a dosage of 1 Gm. daily; dihydrostreptomycin has been used since 1949. Thiosemicarbazone was given in the usual increasing dosage up to a maximum of 0.05 Gm. four times daily. PAS and streptomycin were also used locally, particularly in the cases complicated by empyema and fistula formation. Systematic and regular sensitivity tests were, unfortunately, not carried out. In patients with copious sputum containing a variety of bacteria, sulfanilamides and penicillin were added to the preoperative therapy, and were often combined with inhalation therapy. Depending on the clinical findings, streptomycin was continued for two weeks to one month after operation, and PAS and thiosemicarbazone for at least another month.

Preoperative bronchoscopy was performed in all but seven patients. Analysis of cardiorespiratory function has been carried out on an increasing scale during the last few years. The investigations included determination of total capacity, bronchospirometry, registration of the pressure in the pulmonary artery, cardio-angiography, and estimation of oxygen saturation at rest and during exercise.

The plastic surgery procedures which preceded pneumonectomy and lobectomy were carried out with the aid of local anesthesia. For resection operations, intratracheal anesthesia with spiropulsator respiration was used. Surgery was always performed with the patient in the lateral position. In cases with copious sputum, or where the release of secretions during operation was anticipated, the bronchus was sealed by tamponading. For the last year a double-lumen catheter devised by Carlens has been used. With this technique, anesthesia can be administered to each lung through a separate channel. This is highly advantageous when it is necessary to keep the lungs free of secretion and prevent aspiration from the diseased lung. During operation intravenous drip infusions, mainly blood, were given. In this way, protracted and sometimes difficult dissections, e.g., in pleuro-pneumonectomy, could be performed with the minimum of risk. Bronchoscopic aspiration was carried out as a routine immediately after operation. Apart from the specific chemotherapy, the postoperative management of these cases does not differ from that of other intrathoracic conditions with reference to fluid balance, oxygen administration, chest aspiration and routine roentgenograms.

The complications which may follow operation arise from the specific infection and/or the trauma inflicted by surgery on blood vessels, air passages, and pulmonary parenchyma. To the latter group belong the three pneumonectomies which terminated in fatal surgical shock syndrome. In the survey of complications, the clinical material has been divided into cases with and without specific chemotherapy. Among the lobectomy patients, strangely enough, all the

TABLE II. CLINICAL MATERIAL

	LOBECTOMIES	PNEUMONECTOMIES	
Total patients	22*	32†	54
Men	8	13	21
Women	14	19	33
Age	17 to 63 years	8 to 58 years	
Average age	34 years	34 years	
Duration of disease	1 to 23 years	1 to 24 years	
Average duration	8 years	8 years	
No specific chemotherapy	6	17	23
Specific chemotherapy	16	15	31
Unilateral disease	14	22	36
Bilateral disease	8	10	18
Previous contralateral collapse (pneumothorax)	1	1	2

*Including three cases of combined lobectomy and segmental resection and one segmental resection.

†Including seven pleuro-pneumonectomies.

TABLE III. LOBECTOMIES

INDICATIONS	TOTAL	PREVIOUS ACTIVE THERAPY		NO PREVIOUS ACTIVE THERAPY	BRONCHIAL LESIONS
		PERMANENT COLLAPSE	TEMPORARY COLLAPSE		
Cavities:					
Upper lobe	4	4	0	0	1
Lower lobe	7	1	3+1*	2	2
Upper and lower lobes	1	0	0	1	1
Tuberculous bronchiectasis	4	2	1*	1	1
Tuberculoma	1	0	0	1	0
Suspected tumors†	3	0	0	3	0
Non-specific bronchiectasis	2	0	0	2	0
Total	22	7	5	10	5

*Prophylactic pre-lobectomy thoracoplasty.

†Two tuberculomas, one pulmonary tuberculosis + bronchiectasis.

Three patients not examined by bronchoscopy.

TABLE IV. PNEUMONECTOMIES

INDICATIONS	TOTAL	PREVIOUS ACTIVE THERAPY		NO PREVIOUS ACTIVE THERAPY	BRONCHIAL LESIONS
		PERMANENT COLLAPSE	TEMPORARY COLLAPSE		
Failed cavity closure	2	1	1	0	0
Bronchostenosis with bronchiectasis	17	11	3	3	17
Extensive unilateral lesions	5	0	2	3	1
Empyema with pleurocutaneous fistula	2	2	0	0	1
Residual cavity + empyema + bronchial fistula	4	4	0	0	1
Empyema + bronchial fistula	1	0	1	0	1
Arteriobronchial fistula	1	0	0	1	1
Total	32	18	7	7	22

Four patients not examined by bronchoscopy.

TABLE V. POSTOPERATIVE COMPLICATIONS

POSTOPERATIVE COMPLICATIONS	PNEUMONECTOMIES		LOBECTOMIES	
	WITHOUT CHEMO-THERAPY	WITH CHEMO-THERAPY	WITHOUT CHEMO-THERAPY	WITH CHEMO-THERAPY
Contralateral spread	4	1	0	1
Ipsilateral spread	0	0	0	1
Bilateral spread	0	0	0	1
Tuberculous empyema + bronchial fistula	0	0	0	2
Tuberculous wound fistula	0	1	0	1
Tuberculosis of bronchial stump	1	2	0	0
Staphylococcal empyema	1	1	0	0
Nonspecific wound infection	0	1	0	0
Transient atelectasis	0	0	0	2
Postoperative deaths	6	0	0	1
LATE COMPLICATIONS				
Contralateral spread	0	0	0	1
Ipsilateral spread	0	0	0	1
Bilateral spread	0	0	1	0

TABLE VI. PRESENT STATUS

TIME OF OPERATION	NUMBER OF PATIENTS	CLINICALLY WELL SPUTUM NEGATIVE	CARDIO-RESPIRATORY INSUFFICIENCY	ACTIVE OR POSSIBLY ACTIVE DISEASE* SPUTUM		DEAD
				POS.	NEG.	
26 Pneumonectomies						
1935-1942	(6) 6	5	3	0	0	1
1943-1947	(8) 3	2	0	1	0	0
1948-1949	(8) 7	7	2	0	0	0
1950	(10) 10	8	0	1	1	0
Total	(32) 26	22	5	2	1	1
				3		
21 Lobectomies						
1935-1942	0	–	–			–
1943-1947	(5) 5	2	0	1	0	1
1948-1949	(9) 9	7	0	0	1	0
1950	(8) 7	5	0	1	1	0
Total	(22) 21	14	0	2	2	1
				4		

In the lobectomy group no information is available in two cases.

The figures in parentheses represent the original number of patients in the study.

*In the sputum-negative patients in this group there is manifest or suspected roentgenographic activity.

complications are registered in the chemotherapy group. This, however, is explained by the fact that only six of the twenty-two lobectomy patients received no chemotherapy. Moreover, the complications of ipsilateral and bilateral spread and the two cases of empyema are accounted for by only two patients; one of these had segmental resection, and the other segmental resection with lobectomy. In the latter patient the tubercle bacilli were almost entirely resistant to both PAS and streptomycin. In the case where a tuberculous wound fistula developed, all available chemotherapy had also been fully utilized prior to operation. Contralateral spread occurred in one patient and transient atelectasis in two.

In the pneumonectomy patients, spread occurred in four who had received chemotherapy and in one who had not. Despite the high incidence of bronchial lesions, tuberculosis of the bronchial stump appeared in only three patients. Two of these patients had received chemotherapy. Staphylococcal empyema developed in one treated and one untreated patient. Nonspecific wound infection occurred in one treated patient.

Of the postoperative deaths, three have already been reported as due to surgical shock. None of the three remaining patients who died after pneumonectomy had received chemotherapy: they developed extensive contralateral spreads which could not be controlled and became caseous. In one lobectomy patient, fistula formed and empyema developed with bilateral spread and finally hemoptysis and death. Of the seven patients who died, four must be regarded as poor surgical risks.

Twenty-one lobectomy patients thus survived operation, but one of them died of cardiac disease three years later. Two are known to be alive but no information is obtainable as to their present condition. Fourteen show no clinical or roentgenological signs of active tuberculosis and four are considered as still having active disease. In two of these four patients no thoracoplasty was performed over the excised lobe. Overdistention of the remaining pulmonary parenchyma may therefore have been a significant factor in the occurrence of spread. It is interesting, in this connection, to note that a number of patients who during recent years underwent lobectomy or pneumonectomy for other nontuberculous conditions, developed tuberculous lesions or exacerbations in the overdistended parenchyma. None of these patients was observed to have cardiorespiratory insufficiency.

Of the twenty-six patients who survived pneumonectomy, one died of staphylococcal empyema two years after surgery. Of those now alive, twenty-two show no clinical or roentgenologic evidence of active disease, and three are classed as "not healed." Two of these three patients have positive sputum. The five cases of cardiorespiratory insufficiency are also registered in the pneumonectomy group. This condition is not verified in any case, but is recorded on the basis of information supplied by the patient himself. The patients classified as "not healed" have developed spreads or are assessed as uncertain on other grounds. They are at present receiving temporary collapse therapy or sanatorium care.

During recent years, one or more sputum cultures or gastric washings have always been examined for *M. tuberculosis* after operation. Unfortunately, no uniform plan has been followed. With regard to those patients who underwent operation a number of years ago, reliance has had to be placed to a certain extent on routine direct smears or sputum concentrates.

CONCLUSIONS

Specific chemotherapy has made an important contribution to the good results obtained. Patients previously considered to have a hopeless prognosis

were converted to a more favorable condition for further therapy. This means that an ever-increasing number of patients is prepared for surgery. Chemotherapy must, however, be employed in such a way that its action is not dissipated at the time of the planned operation. For this it is important that there should be close cooperation between the sanatorium physician and the thoracic surgeon in planning the course of therapy at an early stage. Resection of pulmonary parenchyma is followed by overdistention and emphysema of the remaining pulmonary tissue, and the risk of spread is thereby increased. It has therefore been considered advisable to perform thoracoplasty over the site of the excised tissue. Few exceptions have been made to this rule, and these have resulted in one or two serious reverses. In recent years we have performed primary resection only in those cases where preliminary thoracoplasty was considered to be precluded by the toxicity of the disease and the patient's poor general condition. Thoracoplasty was performed when the patient's condition had sufficiently recovered.

Segmental resection should be reserved for well-defined and localized lesions with little or no activity. Otherwise there is considerable risk of fistula formation, empyema, and spread of the disease.

Careful testing of function should precede operation in every case where it is important to conserve functioning parenchyma and avoid a more disabling cardiorespiratory insufficiency.

In the light of our present experience, resection therapy in pulmonary tuberculosis appears to be a necessary and advisable complement to collapse therapy in suitable cases. Pulmonary resection does not involve a greater surgical mortality or risk of complications than surgical collapse therapy in general. It may be directly lifesaving in cases of unilateral disease with grave general toxicity where other methods of treatment are out of the question: stenosis of the main bronchus with complete pulmonary destruction constitutes such an indication.

SUMMARY

A report is presented of a series of resection operations carried out on patients with pulmonary tuberculosis at Sabbatsberg Hospital, Stockholm, during the period 1935-1950. The series comprised thirty-two pneumonectomies, twenty lobectomies, and two lobectomies combined with segmental resection. The main indications were: (1) failure of collapse therapy to effect cavity closure; (2) pulmonary lesions secondary to stenotic bronchial tuberculosis; and (3) extensive parenchymatous lesions.

Prior to 1948, nineteen patients underwent operation without the protection of specific antimicrobial agents. There were seven deaths in this group, six of which occurred in the immediate postoperative period.

The thirty-five patients submitted to operation since the beginning of 1948 received specific medication. One of these patients died in the immediate postoperative period, and one later.

The present condition of the surviving patients is reviewed.

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ANGIOGRAPHIC STUDIES AFTER PULMONARY RESECTION

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DURING the last few years the field of thoracic surgery has developed new techniques on pulmonary resection, from segmental resection to pneumonectomy; at the same time both surgeons and physiologists have become more interested in the knowledge of the functional state of the rest of the pulmonary tissue, as the patient requires a correct hematosis to continue living.

Many investigators have been concerned with the problems of research including functional, spirometric, and bronchospirometric studies after the therapeutic methods which reduce the field of hematosis (collapse therapy, pneumonectomy, etc.) have been used. Cournand and Richards,[1] in 1941, stressed the effect of various types of collapse therapy upon cardiopulmonary function, and observed a decrease in the maximal breathing capacity after exercise. The same observations were made by Cicero[2] in his receptional thesis in respect to extrapleural pneumothorax. Cournand and Riley[3] in 1950 reported sixteen cases, seven of which were seen shortly after pneumonectomy and nine long after they had been subjected to this therapeutic procedure; in the first group there was a less marked decrease in the maximal breathing capacity after exercise than in the second. Burnett and Long[4] reported a decrease in the maximal breathing capacity in twenty-four patients after they had been pneumonectomized. Long and Norris[5] performed bronchospirometric studies in bronchiectasis before and after lobectomy in sixty-four patients, in some cases there was no variation in the maximal breathing capacity, while in other cases there was an increase. Taylor, Roos, and associates,[6] in their paper on "Respiratory and Circulatory Studies in Patients after Bilateral Lobectomy" reported ten cases in which there was a decrease, both in the maximal breathing capacity and in the oxygen saturation. Peters, Roos, and associates[7] studied ten children after they had been pneumonectomized, and observed that both the oxygen saturation and the maximal breathing capacity gave almost normal values, and concluded that there is no relation between the time in which the operation was performed and the functional state of the rest of the pulmonary tissue, as long as adequate training was carried out in these patients tending to maintain the mobility of the diaphragm and mediastinum.

In most of the cases roentgenologic studies of the chest some time after lobectomy are unable to give information as to the functional state of that lung in as much as the other lobes tend to re-expand and fill the place left in the thoracic cavity, the diaphragm returns to its normal position; in some cases the shadow cast by the lung parenchyma may be less dense due to overdistention.

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In young patients and in those in whom there are no postoperative complications such as broncho-pleural fistulas or empyemas, the roentgenogram of the chest seems to be that of a normal subject.

The visualization of the pulmonary vessels may give some information as to the functional state of the pulmonary tissue left and Neuhof and Nabatoff have already used angiography[8] to study the form and function of the remaining lung after pneumonectomy. Keil and Schissel[9] using the same method were able to make the differential diagnosis of unresolved pneumonia and bronchiogenic carcinoma.

The technique of angiography which we used is the one first described by Dr. Celis which consists in the introduction of a Nelaton's type of catheter through the external jugular vein in the neck down to the right cardiac chambers or stem of the pulmonary artery, injecting 30 or 40 c.c. of 80 per cent Nosylan and taking a roentgenogram half a second after the opaque substance has been injected, thus obtaining the image of the stem of the pulmonary artery and its main branches.

In a normal person being subjected to angiographic study in the antero-posterior position, the stem of the pulmonary artery arising from the conus arteriosus of the right ventricle extends obliquely upward and backward, and after a short course is divided into right and left branches. The first, longer and larger than the second, runs horizontally to the right to the root of the right lung. The left branch passes backward and slightly outward, lying axially to the frontal plane. The right branch of the pulmonary artery gives off its first branch to the upper lobe at the root of the right lung where it bends, showing a curve concave externally thus making it a descending artery, and constitutes the blood supply of the apical and anterior segments; the branch of the posterior segment arising from the stem runs outward; the two branches which supply the middle lobe arise somewhat lower and inward; the branch which supplies the dorsal segment arises outward, while the basal branches are given off downward. The left branch of the pulmonary artery, shorter and somewhat smaller than the right, has a more atypical distribution, most of the anatomists consider from three to seven branches for the upper lobe, while it is not possible to determine the number from an angiographic point of view. In some cases the main branch shows only a common stem, in other cases several secondary branches arise directly from the main stem; immediately downward and outward is the branch to the lingular lobe, the branch of the dorsal segment arises in front and inward, and the basal branches arise downward. All of these arterial branches give off more branches as they run to the periphery, thus originating a "rich and complete circulation."[11]

In the lateral position the same distribution may be seen, only that the shadows cast by both pulmonary arteries are superimposed, thus making it difficult to identify the branches of each pulmonary artery.

The angiographic study gives valuable information as to the functional state of the pulmonary vessels and mediastinum:

1. Position of the pulmonary artery; in pneumonectomized patients we have observed that the pulmonary artery and mediastinum are displaced toward

the operated side if no method, such as thoracoplasty or filling of the cavity with plastic material, is carried out to prevent such a displacement which causes overdistention of the other lung, and consequently a state of respiratory insufficiency.

2. Section of the corresponding arterial branch; this is purely anatomic and is manifested by a sudden stop of the opaque substance at the place of the sectioned branch.

3. Separation of the arterial branches; this is due to the cavity left and overdistention of the remaining lobes or lung, the arterial branches seem to be less and more separated than normally, indicating a poor blood supply and consequent defect in the hematosis; the angiogram after pulmonary resection differs from that in pulmonary emphysema in which there is a diminished blood supply at the periphery.

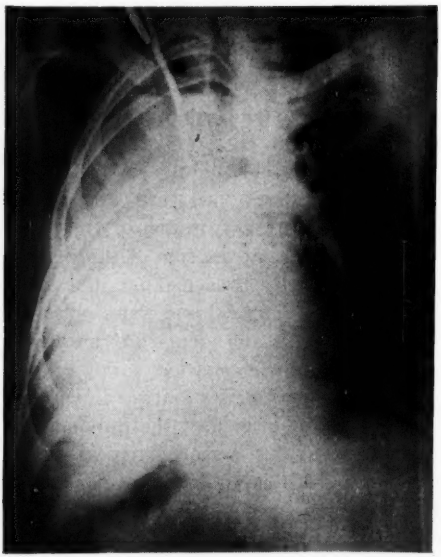

Fig. 1.—Case 1, F. O. Right pneumonectomy (tuberculosis). Angiogram taken three months after the operation. The pulmonary artery is displaced toward the operated side; its left branch is elongated.

We are reporting thirteen cases of pulmonary resection in which angiographic studies were made. The patients in our series were from 18 to 50 years of age, nine men and four women; three patients were pneumonectomized, two of them due to tuberculosis and one due to bronchiectasis with abscess formation; in the other ten cases lobectomy was performed (two lobes in four cases), four were bronchiogenic cysts infected, one inflammatory stenosis of the lower left bronchus, one carcinoma of the lower left bronchus in which a palliative lobectomy was performed as the bronchial obstruction produced the formation of a distal abscess, two bronchiectasis, one abscess, and one tuberculosis.

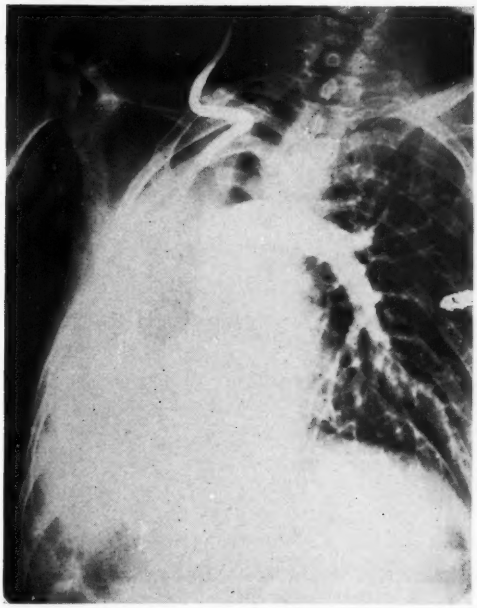

Fig. 2.—Case 2, D. H. Right pneumonectomy (bronchiectasis with abscess formation). Angiogram taken two years and four months after the operation. The displacement of the pulmonary artery is more marked than in the former case (Fig. 1); the pulmonary artery is longer and its branches are more separated.

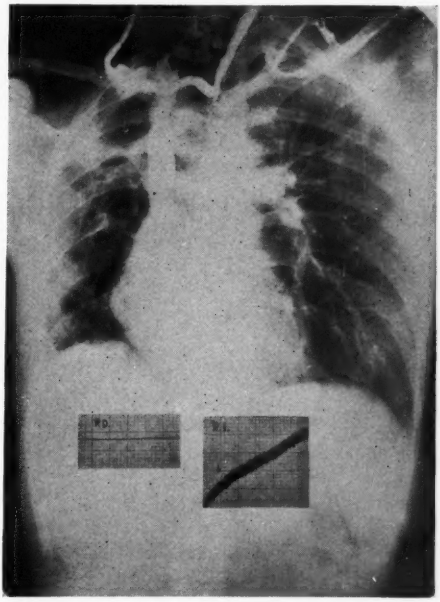

Fig. 3.—Case 12, M. V. Angiogram taken before the patient was operated. Notice the normal position of the mediastinum.

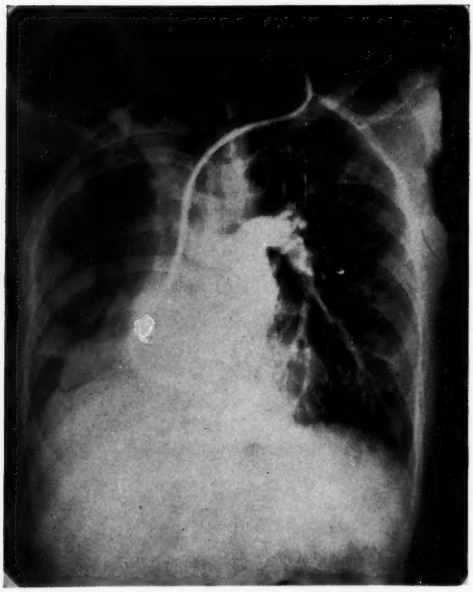

Fig. 4.—Case 12 after right pneumonectomy (pulmonary tuberculosis). Angiogram taken eighteen days after operation. The mediastinum is not displaced. The right branch of the pulmonary artery is sectioned.

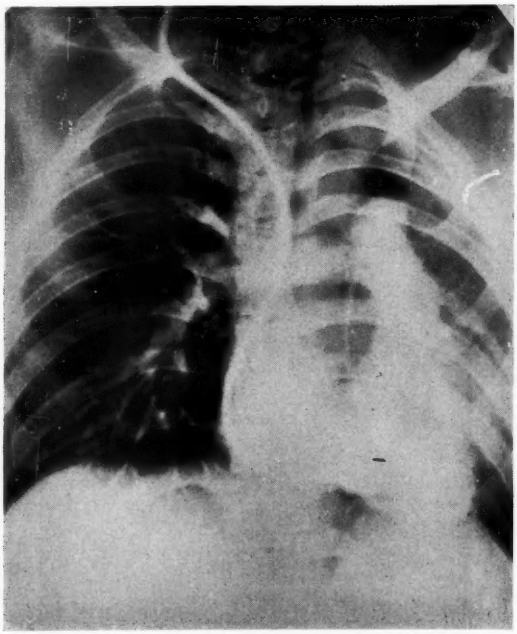

Fig. 5.—Case 3, R. M. Lobectomy of the upper left lobe (cyst). Angiogram taken one year and four months after the operation. The pulmonary artery is displaced toward the operated side, the blood supply is diminished. This patient developed a postoperative empyema.

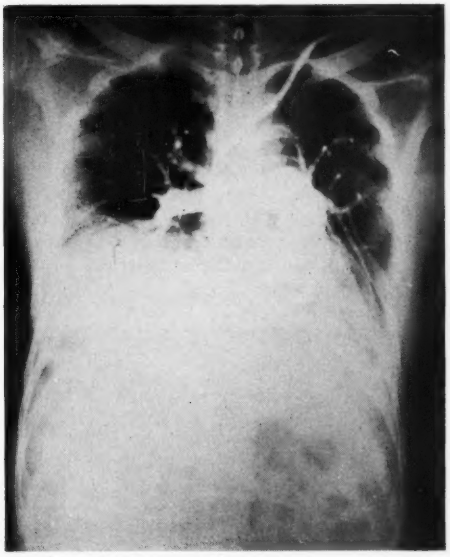

Fig. 6.—Case 8, C. G. Bilateral lobectomy (bronchiectasis). There is a diminished blood supply in both lungs.

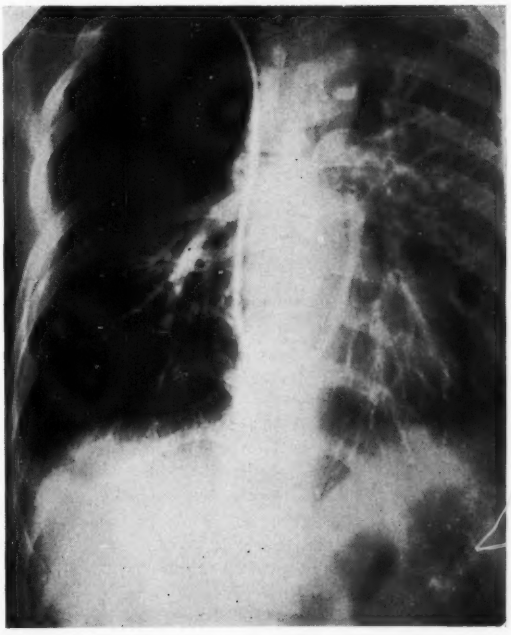

Fig. 7.—Case 7, Q. L. Lobectomy of the right upper lobe (cyst). Right pneumothorax. The blood supply to the rest of the pulmonary tissue appears to be normal.

The cases studied are divided into two groups: (1) pneumonectomized patients, and (2) lobectomized patients. In the first group we report three cases. CASE 1.—F. O. (Fig. 1) on whom the operation was performed three months before the angiographic study. The pulmonary artery is displaced toward the operated side, its left branch is elongated, its smaller branches show diastasis, and the blood supply at the periphery is somewhat diminished. CASE 2.—D. H. (Fig. 2) in which angiographic studies were made two years and four months after pneumonectomy (right lung), the pulmonary artery suffered a marked displacement toward the operated side. There is a considerable dilatation, and its walls are elongated; its branches at the periphery of the lung pass through the mediastinum, and there is a separation between them. The third case (number 12 in Table I), M. V. (Figs. 3 and 4), was studied before pneumonectomy and eighteen days after the operation. There are no visible changes; the pulmonary artery is in its normal position, and its branches seem to be normal.

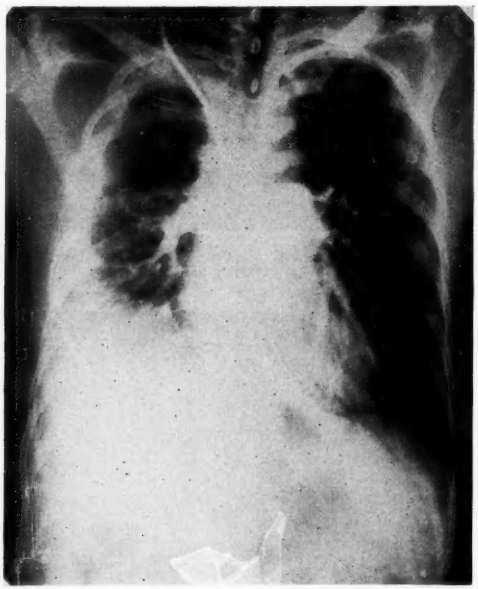

Fig. 8.—Case 9, M. S. Lobectomy of the right upper lobe (abscess). There is no alteration of the pulmonary artery as compared with the opposite side.

In the rest of the cases lobectomy was performed; CASE 3.—R. M. (Fig. 5), an 18-year-old patient on whom angiographic studies were made one year and four months after the operation, shows the pulmonary artery to be displaced toward the operated side, and a diminished blood supply to the rest of the lobes. It is interesting to note that this patient developed an empyema which was later treated by open drainage, and finally the total re-expansion of the other lobes was obtained. CASE 8.—C. G. (Fig. 6) had bilateral lobectomy and was studied four months after the first operation and twenty days after the second, the stem of the pulmonary artery is not displaced although there is a diminished blood supply at the bases. CASES 7 and 9.—Q. L. (Fig. 7) and M. S. (Fig. 8), on whom the rest of the lobes did not re-expand after the operation and, when the angiographic studies were made, they were seen to have pneumothorax. There is no displacement of the pulmonary artery, and its branches are not separated nor the blood supply diminished in the other lobes. In the rest of the cases there is a diminished blood supply to the lobe or lobes extirpated (Figs. 9 and 10).

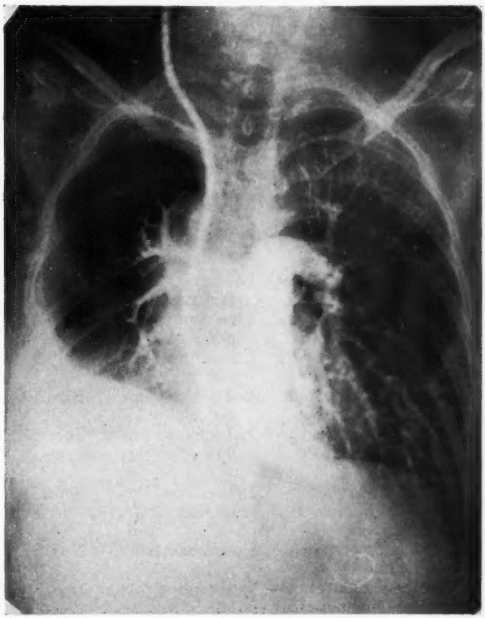

Fig. 9.—Case 11, R. B. Lobectomy of the lower and middle lobes (tuberculosis). Pulmonary hyperillumination, diminished circulation.

Fig. 10.—Case 13, A. A. Lobectomy of the left lower lobe (bronchiogenic carcinoma with distal abscess formation). Pulmonary hyperillumination, there is also a diminished circulation.

TABLE I

NAME	AGE	SEX	DIAGNOSIS	TYPE OF OPERATION	DATE	DATE OF ANGIOGRAPHY
1. F. O.	25	M	Right pulmonary tuberculosis	Pneumonectomy, right	Feb. 2, '46	Jan. 1, '47
2. D. H.	38	F	Right bronchiectasis and abscess	Pneumonectomy, right	Jan. 29, '48	June 13, '50
3. R. M.	18	M	Cyst, upper left lobe	Lobectomy, upper left	June 30, '49	Oct. 13, '50
4. N. V.	20	M	Cyst, right upper lobe	Lobectomy, upper right	Nov. 15, '49	May 26, '50
5. E. H.	34	F	Cysts, upper and middle lobes	Lobectomy, upper and middle	Feb. 9, '50	May 30, '50
6. I. E.	30	M	Bronchiectasis, lower and middle lobes	Lobectomy, lower and middle	March 2, '50	April 15, '50
7. Q. L.	26	M	Cyst, upper right lobe	Lobectomy, upper right	April 22, '50	May 22, '50
8. C. G.	45	M	Bronchiectasis, lower and middle left	Lobectomy, lower and middle	July 10, '50	Dec. 7, '50
9. M. S.	35	M	Abscess, upper right lobe	Lobectomy, upper right	Nov. 18, '50	Aug. 17, '50
10. J. Z.	18	M	Inflammatory stenosis, lower left bronchus	Lobectomy, lower left	July 15, '50	Oct. 31, '50
11. R. B.	29	F	Pulmonary tuberculosis, right lower and middle	Lobectomy, lower middle	Sept. 19, '50	Dec. 13, '50
12. M. V.	26	M	Right pulmonary tuberculosis	Pneumonectomy, right	Nov. 27, '50	Dec. 15, '50
13. A. A.	50	F	Carcinoma, lower left bronchus, also abscess	Lobectomy, lower left	Dec. 5, '50	Dec. 20, '50

DISCUSSION

In the cases we studied no method was used to fill the cavity remaining after pneumonectomy or lobectomy; instead the rest of the pulmonary tissue was left to re-expand and fill the space left after the operation. We observed that in all cases the lung tends to expand, thus representing more tissue surface to be supplied, as demonstrated by angiography, with the same number of blood vessels since these are unable to multiply themselves, giving rise to a respiratory insufficiency in the affected lung.

We observed also that both the pulmonary artery and mediastinum tend to be displaced toward the pneumonectomized side, and that such a displacement, also found in cases of postoperative complications, is more marked as time passes.

In the cases with pneumothorax there is no alteration of the pulmonary vessels, since the presence of the pneumothorax acts to prevent the overexpansion of the remaining pulmonary tissue.

CONCLUSIONS

1. We use angiography as a method of studying the function of the lung.

2. With this method we are able to observe the alterations which pulmonary resection produces in the mediastinum.

3. The angiogram gives information as to the state of the mediastinum and pulmonary vessels when the patient has developed postoperative complications.

4. The mediastinal displacement is more marked the longer the time between pneumonectomy and the angiographic study.

5. Allowing the rest of the lobes or the other lung to re-expand and fill in the cavity left after lobectomy or pneumonectomy gives rise to a state of respiratory insufficiency.

6. The substitution of the lung tissue extirpated by a collapse method may be useful to prevent the total re-expansion of the rest of the pulmonary tissue.

7. We condemn pneumonectomy from a functional point of view, and advocate the extirpation of as little pulmonary tissue as the disease may allow in order to prevent respiratory insufficiency.

SUMMARY

Thirteen cases of pulmonary resection (lobectomy or pneumonectomy) are presented in which angiographic studies were made. After pneumonectomy, the mediastinum is found to be displaced toward the operated side. Such a displacement is more marked the longer the time between the operation and the time in which angiography is performed. In lobectomized patients there is a diminished blood supply to the rest of the lobes as shown by the angiograms. In all cases there is an overdistention of the other lung after pneumonectomy, or other lobes after lobectomy.

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SPONTANEOUS CONTRALATERAL PNEUMOTHORAX COMPLICATING THORACIC SURGICAL PROCEDURES

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THE general trend of reduced mortality and morbidity following thoracic surgical procedures during the past two decades has created a challenge for the further betterment of operative results. This report is being made to record additional cases and re-emphasize the potential danger of an uncommon serious postoperative complication which, if recognized and treated promptly, can favorably alter the course of the few patients in whom it may occur.

REVIEW OF LITERATURE

A review of the surgical literature reveals relatively few references to spontaneous contralateral pneumothorax following thoracic operations. In 1936, Coryllos and Ornstein[3] reviewed the complications of the surgical treatment of bilateral pulmonary tuberculosis and discussed a situation which was similar in some respects to the complication which forms the basis for this report. In performing thoracoplasty on a group of patients with bilateral tuberculosis, an artificial pneumothorax was maintained on the opposite side. Twenty-two instances of superimposed collapse of a spontaneous nature occurred on the contralateral (pneumothorax) side in the postoperative period, four deaths resulting as a direct consequence of this complication. On the basis of thoracoscopic examinations, the etiologic mechanism was found to be an apparent rupture of an emphysematous bleb on the surface of the partially collapsed lung. This mechanism is taken up subsequently in the discussion of etiology. However, we are concerned at the present time with the incidence of spontaneous pneumothorax, with or without a tension factor, on the contralateral side or "good lung."

Stephens'[8] report is the earliest available description in detail of contralateral pneumothorax following intrathoracic operations. (See Table I and the review of reported cases.)

In his detailed review of 345 cases of bronchiogenic carcinoma, Bjork[2] analyzed the operative complications in 152 cases in which thoracotomy was performed. No instance of contralateral pneumothorax was recorded. Likewise, an earlier report by Ochsner and DeBakey[7] on surgical considerations of carcinoma of the lung failed to mention any encounter with this unusual post-

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TABLE I. REPORTED CASES

CASE	OPERATION	POSTOPERATIVE OCCURRENCE OF PNEUMOTHORAX	OUTCOME	TENSION FACTOR
1. Stephens—Case I	Exploratory thoracotomy	Operative day	Died	Present
2. Stephens—Case II	Left pneumonectomy	Operative day	Died	Present
3. Stephens—Case III	Lobectomy, right lower lobe	Operative day	Survived	Present
4. Melick and Gutekunst	Left pneumonectomy	60 days postoperative	Survived	Present
5. Gleason and Kent	Lobectomy, left lower lobe	3rd postoperative day	Survived	Absent
6. Case I (this report)	Lobectomy, right upper lobe	2nd postoperative day	Survived	Present
7. Case II (this report)	Open thoracotomy drainage, right	10th postoperative day	Died	Present
8. Case III (this report)	Thoracoplasty, right, 4th (anterior) stage	33rd postoperative day	Survived	Absent

operative episode. Alexander's[1] text on the collapse therapy of pulmonary tuberculosis mentions the possibility of spontaneous pneumothorax occurring on the contralateral side during artificial pneumothorax treatment. He states that an immediately perilous condition may develop, and several cases are described in which this situation occurred. However, contralateral spontaneous pneumothorax is not referred to in the discussion of thoracoplasty complications.

More recent references in the literature are devoted mainly to the few case reports listed in Table I and described in some detail below.

The apparent infrequency of this complication may be due to several factors. The cause for sudden death of a patient in the early postoperative period may not be elucidated without autopsy examination; hence, failure to recognize the actual mechanism involved. Further, without ante-mortem suspicion or outright diagnosis, the pathologist's report may include the findings of "complete atelectasis" or "massive collapse" of the lung without specific effort being made to carefully scrutinize any small emphysematous blebs or the integrity and continuity of the mediastinal wall.

Table I lists the cases available for study and review including the three patients described in this report. A brief summary of each case follows:

Stephens' first case followed a left exploratory thoracotomy for inoperable carcinoma. Five hours postoperatively subcutaneous emphysema appeared, and ten hours later the wound was reopened with the demonstration of an open bronchus. Closed tube drainage was used, but the patient died twenty-five hours postoperatively and the diagnosis of a collapsed opposite lung was made at autopsy.

In the second case reported by Stephens, a left pneumonectomy was performed on a 40-year-old man for bronchogenic carcinoma. The patient died at the completion of the operation when turned over on his back. Autopsy showed the right lung entirely collapsed.

Stephens' third case occurred after a right lower lobectomy for bronchiectasis in a 10-year-old boy. When found that forced positive pressure by the anesthetist was necessary for completion of the operation, a needle was inserted into the left thorax and free air found. This patient survived.

It was assumed that the etiologic factor in each of these three cases of contralateral pneumothorax was a communication to the unoperated side through a probable tear of both layers of the mediastinal pleura. However, such a tear could not be demonstrated in the two cases which came to autopsy.

Melick and Gutekunst[6] reported a case in which a left pneumonectomy was done for tuberculosis complicated by bronchiectasis. Early in the postoperative course marked cardiac arrhythmia occurred which was eventually converted to normal. Sixty days following the operation sudden severe dyspnea developed. Apparently atelectasis was considered the most likely diagnosis, and bronchoscopy performed. However, no evidence of obstruction was found, and the

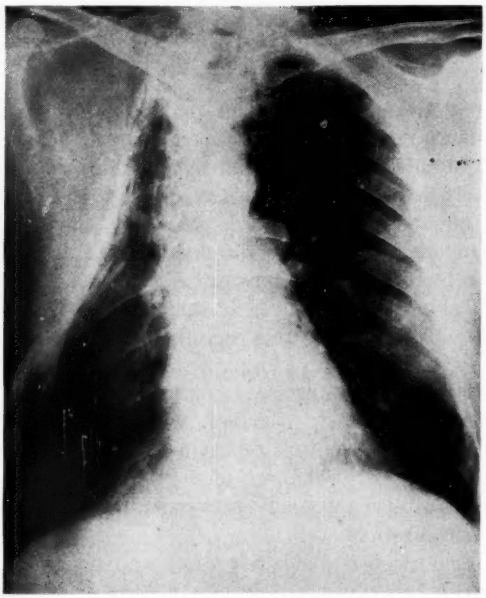

Fig. 1.—Case 1. Preoperative roentgenogram of the chest prior to right upper lobe lobectomy. The left lung presented no abnormal findings.

diagnosis of contralateral tension pneumothorax was confirmed when the chest tap was done. Initial aspirations of air gave only temporary relief of dyspnea so that closed catheter suction was utilized and maintained for thirteen days. Thereafter, the lung remained re-expanded, and recovery was uneventful.

A case has been described by Gleason and Kent[4] in which a left lower lobe resection had been performed for bronchiectasis with the appearance of a right spontaneous pneumothorax on the third postoperative day. The patient manifested only moderate dyspnea without cyanosis. When conservative therapy was ineffective, the chest was opened nineteen days later and a leaking emphysematous bleb excised. Recovery followed. The authors stated that tension pneumothorax with mediastinal shift did not occur, but, had it been present, the respiratory embarrassment would undoubtedly have been much more marked.

REPORT OF CASES

The three cases to be described in some detail occurred on the thoracic surgery service of the Veterans Administration Hospital, Wood, Wisconsin. Two of the cases were observed within a relatively short period of time, and our attention was directed to the dangerous potentialities of this operative complication.

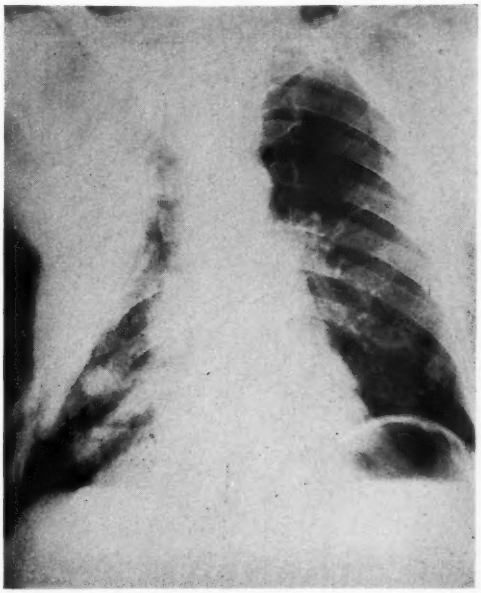

Fig. 2.—Case 1. First postoperative day film following right upper lobectomy showing satisfactory re-expansion on the right and a normal-appearing contralateral lung.

CASE 1.—R. F. (VA No. 125 216), a 53-year-old white man, had had a seven-rib right thoracoplasty for tuberculosis completed in 1947. His sputum remained negative until November, 1949, when it again became positive (Fig. 1). Resectional surgery was recommended but delayed because of a surprisingly low respiratory reserve. The ventilatory studies revealed the following:

Reserve air	644	Expected MBC	102.4
Complementary air	1577	Per cent of expected	50%
Vital capacity	2033	Walking ventilation	13.22
Maximum breathing capacity	51.06	W. V./MBC	0.26

Bronchospirometry showed 25 per cent oxygen consumption on the right, 75 per cent on the left.

A right upper lobectomy was performed (W. W.) on Jan. 31, 1951, under general anesthesia with endotracheal intubation. The operation was completed without unusual event, but it was specifically noted that the mediastinal wall was fairly rigid and "frozen." The postoperative condition was satisfactory, and the portable bedside roentgenogram showed good expansion of the right middle and lower lobes and the left lung to be negative. The first postoperative day was likewise uneventful with two drainage tubes functioning well with connection to water sealed drainage bottles (Fig. 2). On the morning of the second post-

operative day, the temperature was recorded as 98.6° F., pulse rate 120 per minute, and moderate dyspnea noted, with slight subcutaneous emphysema of the neck extending up to the left side of the face. At 4:00 P.M. in the afternoon the dyspnea became marked, cyanosis evident, and little relief afforded by an oxygen mask conveying 8 liters per minute. Cursory examination showed the drainage tubes on the right (operative side) to be open and functioning; the left chest was tympanitic with evidence of mediastinal shift to the right, the point of maximum cardiac impulse being palpated at the left border of the sternum. During the examination the patient's condition became progressively more critical with extreme dyspnea,

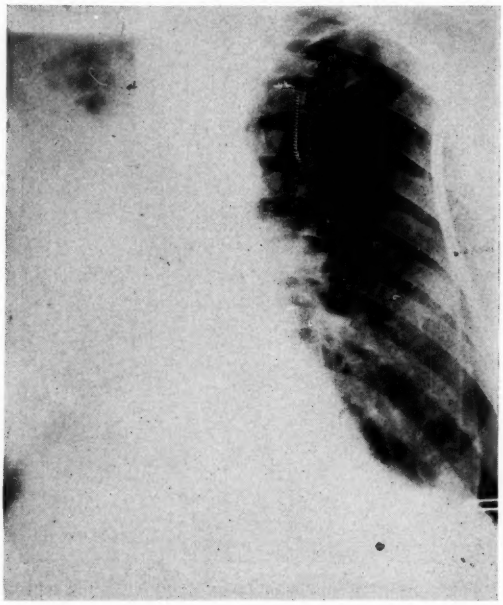

Fig. 3.—Case 1. Roentgenogram taken on the 6th postoperative day, four days after the spontaneous contralateral pneumothorax. The catheter can be visualized in the left pleural space. Note the right lower lobe atelectasis requiring bronchoscopic aspiration.

leading to gasping, infrequent respiratory efforts, unconsciousness, and a weak almost imperceptible pulse. The portable x-ray machine was set up in the recovery room, but the actual film was not taken when the diagnosis was realized, with the fear that the few minutes spent adjusting the cassette and the machine would be disastrous. Immediate thoracentesis was carried out in the second left interspace anteriorly; free air under pressure was found in the pleural space. With negative suction on the needle, large volumes of air were aspirated, and a trocar was inserted just lateral to the needle allowing installation of a catheter connected to continuous suction with an intervening water seal bottle. Dramatic improvement followed, and within twenty minutes the patient recovered sufficiently to speak, remove his oxygen mask, and cough. Subsequent portable roentgenograms showed almost complete re-expansion of the left lung with the catheter in place (Fig. 3). The patient's condition remained critical, however, for the next few days with atelectasis developing in the right middle and lower lobes necessitating daily bronchoscopic aspiration. After progressive clearing of the right side, continued expansion of the left side, and loss of the subcutaneous emphysema, the tubes were removed from the right side on the fourth postoperative day and the catheter from the left side on the eighth postoperative day. Three hours after the

catheter from the left pleural space had been removed, signs and symptoms of recurrence of the left tension pneumothorax and mediastinal shift became apparent. Being prepared for this possibility a roentgenogram was obtained and a catheter reinserted promptly (Fig. 4). Following this episode, the catheter suction was maintained for twelve days, and, following removal, the left lung remained fully expanded with progressive recovery (Fig. 5).

Gross examination of the surgically removed lobe revealed a tuberculous cavity 1.5 cm. in diameter. Over the apical portion multiple small bullae and blebs measuring 0.5 cm. in diameter were found. Micro sections revealed tuberculosis, and, peripherally, marked emphysematous changes with dilatation of the alveoli and rupture of the alveolar sacs.

Fig. 4.—Case 1. Recurrence of the pneumothorax on the left following removal of the intrapleural catheter on the eighth postoperative day.

CASE 2.—G. K. (VA No. 126 540), a 33-year-old white man, was admitted to the thoracic surgical service with a right empyema treated at another hospital by open thoracotomy drainage. A bronchopleural fistula had developed, and the right lung was but 50 per cent expanded. The patient was chronically ill, and his subsequent course was a long and difficult one. On Dec. 26, 1950, a decortication of the right lung and a right middle lobectomy (W. W.) were performed. A stormy postoperative course followed with retraction of the lung and accummulation of pleural fluid (Fig. 6). Open thoracotomy became essential, and this was done on Feb. 13, 1951. A large Fryer type rubber tube was used to maintain the open drainage and the postoperative course was satisfactory, with progressive improvement in his general condition. On the tenth postoperative day at 4:30 P.M. he noted persistent mild dyspnea and, following his evening meal, the dyspnea suddenly became severe. When seen by the resident physician he was sitting up in bed, breathing with extreme difficulty; no cyanosis was evident, the pulse rate was 120 per minute, and regular. Examination of the left chest revealed some flatness to percussion over the left paravertebral region, distant breath sounds on auscultation with no râles or other adventitious sounds, and evident use of the accessory muscles of respiration. Oxygen therapy was begun as soon as the patient was seen, and a portable bedside chest roentgenogram was taken. Dyspnea increased and cyanosis appeared.

With a tentative diagnosis of tracheal or bronchial obstruction, an attempt was made to pass an endotracheal tube but was unsuccessful due to the onset of convulsive movements with muscle rigidity. A tracheotomy was performed immediately, endotracheal suction being instituted along with artificial respiration. He failed to respond to these measures, and died approximately fifteen minutes after the onset of the acute symptoms. The roentgenogram mentioned above (Fig. 7) was not developed in time to be read before the patient's demise.

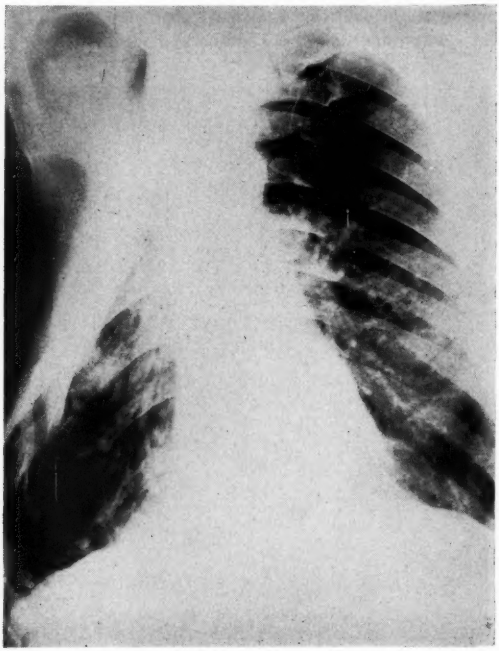

Fig. 5.—Case 1. Full re-expansion of the left lung after a total of eighteen days' intrapleural catheter suction.

Autopsy examination was preceded by the usual method of demonstrating tension pneumothorax: an incision over the left second interspace anteriorly with elevation of the wound edges produced an excavation which was filled with water. Incision through the intercostal muscles and pleura allowed sudden outward gushing release of the air under tension. The left lung was found completely collapsed. Over the apex of the left upper lobe, numerous small emphysematous bullae were present, one of which, measuring 1.5 cm. in diameter, was found to be ruptured. The site of rupture was immediately adjacent to the attachment of a narrow adhesive band, the opposite end of the band being fixed to the parietal pleural surface in the apical area. No tear of the parietal pleura could be found. After removal of the left lung, re-expansion under water demonstrated the exit of air from the ruptured site.

Case 3.—E. M. (VA No. 105 474), a 29-year-old white man, who had a diagnosis of pulmonary tuberculosis made in 1943. As a patient in a U. S. Naval Hospital, artificial pneumothorax on the left was instituted in March, 1943, and maintained until February, 1948. Pneumonolysis was carried out on the left in May, 1943, and again in July, 1943. The sputum and gastrics had become negative following collapse therapy and remained negative until

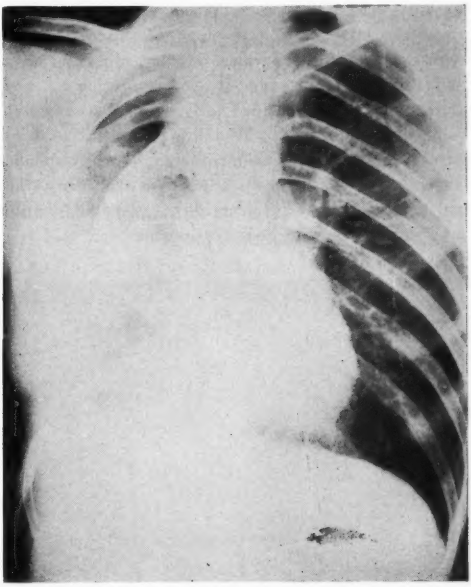

Fig. 6.—Case 2. Chest roentgenogram prior to open thoracotomy drainage on the right. The left lung appeared normal.

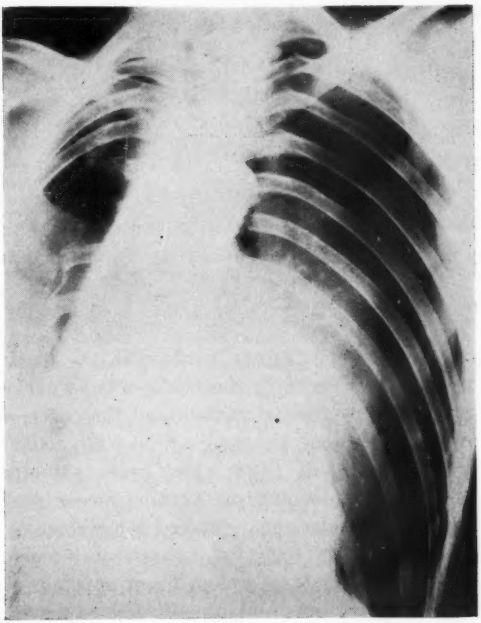

Fig. 7.—Case 2. Portable bedside chest roentgenogram not seen ante mortem, revealing the marked collapse of the left lung.

February, 1948. The patient was admitted to Wood Veterans Administration Hospital in June, 1948, at which time the left artificial pneumothorax was discontinued. Re-expansion was satisfactory, and subsequent roentgenograms revealed fibrocaseous tuberculosis involving the right upper lung, with several areas suggestive of cavitation. A course of streptomycin was given and right thoracoplasty recommended (Fig. 8). A six-rib right thoracoplasty was performed in stages, being uneventful, up to his ninth postoperative day when he complained of dyspnea. Fluoroscopy revealed a left pneumothorax which responded favorably to one aspiration and the lung was completely re-expanded. On the thirty-third postoperative day following his last stage, the pneumothorax recurred (Fig. 9) and, although symptoms were minimal, it required three successive aspirations for re-expansion.

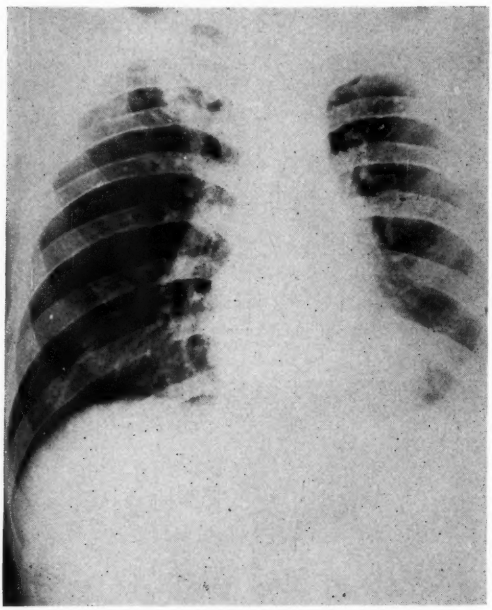

Fig. 8.—Case 3. Roentgenogram of the chest taken prior to the performance of thoracoplasty on the right side. The left lung showed some pleural thickening.

DISCUSSION

With regard to the etiologic factors involved in the production of a spontaneous contralateral pneumothorax in the postoperative period, several mechanisms have been proposed. Stephens[8] maintained that each of his three cases was due to communication through the mediastinal wall, although the site could not be demonstrated in the two cases which were examined post mortem. Knoepp,[5] in discussing the importance of various mechanical and circulatory postoperative pulmonary complications, devoted some attention to spontaneous pneumothorax, but the only reference to contralateral tension pneumothorax following thoracic surgical procedures was a direct notation of Stephens' work. He also believed the mechanism was undoubtedly due to tearing the mediastinal pleura during the operative dissection. Melick and Gutekunst[6] did not suggest

what the causative factor might have been in their cases. On the other hand, a ruptured emphysematous bleb was proved to be responsible in Gleason and Kent's[4] report. We have considered this latter mechanism to be the most feasible in each of the cases reported herewith.

In Case 1, several possibilities had to be considered: (1) an air leak at the lobectomy site with communication through both layers of mediastinal pleura; (2) a pleural tuberculous lesion on the contralateral side; and (3) a ruptured emphysematous bleb with or without an adjacent adhesive band and simultaneous parietal pleural tear. After consideration of the various aspects of the case and review of the operative and pathologic findings, the third mechanism seems most appropriate. In Case 2, this mode of production of the pneumothorax was adequately demonstrated at autopsy as described above. Acceptable

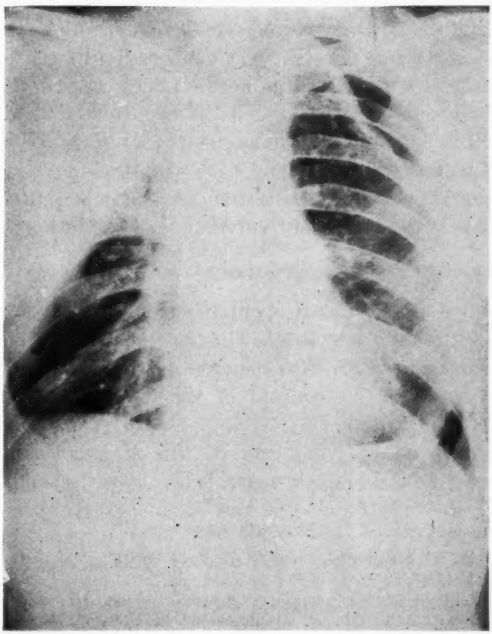

Fig. 9.—Case 3. Spontaneous contralateral pneumothorax on the left occurring thirty-three days following the last stage of thoracoplasty on the right.

evidence of the mechanism involved in Case 3 was lacking for a long time until the patient returned to the surgical service for collapse therapy for disease in the left apex. During the course of preliminary intrapleural poudrage and subsequent extrapleural lucite ball plombage, several large blebs were visualized in the apical area, the presence of which allowed circumstantial although indirect proof of the etiology of his previous spontaneous pneumothorax. Hence, on the basis of our experience with these few cases and the additional cases available for study, we believe that the ruptured emphysematous bleb assumes a predominant role in the etiology of this serious postoperative complication.

Alexander,[1] in discussing perforation of the lung, has stated that any diagnostic measure which is not at the same time capable of relieving the symptoms of respiratory embarrassment is contraindicated. This statement implies that clinical indications must suffice to warrant the confirmatory diagnostic and likewise therapeutic application of immediate thoracentesis. Roentgenograms or fluoroscopy permit the loss of valuable time, and occasionally a patient's life. The validity of Alexander's statement is well demonstrated in Cases 1 and 2. In the first case the portable x-ray machine was actually being adjusted in the recovery room when the danger of the "time lost" factor was realized and definitive treatment carried out on the basis of the physical findings. In the second case, where death supervened fifteen minutes after onset of severe symptoms, the clinical picture was thought to be due to an obstructed airway and the patient treated accordingly. Time was taken to obtain a bedside roentgenogram of the chest, but the patient expired even before the film could be developed.

Treatment is simple and effective. Decompression of the pleural space by immediate thoracentesis with any large needle allows release of the high intrapleural pressure, correction of the mediastinal shift, and prompt relief from the severe subjective symptoms. Subsequent placement of an intrapleural catheter provides a satisfactory method of evacuating the air and connection to a continuous suction device. Thereafter, the management of the situation corresponds to that of any ordinary valvular pneumothorax.

SUMMARY

1. Three cases of contralateral spontaneous pneumothorax following thoracic surgical procedures are described. The few instances of this operative complication previously reported are also reviewed.

2. Additional basis for the concept of the ruptured emphysematous bleb as an etiologic factor is recorded.

3. The awareness of the possibility of this serious complication by the thoracic surgeon and the resident physician is necessary to avoid mortality.

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INTRATHORACIC MENINGOCELE: EXCISION, WITH THREE AND ONE-HALF YEARS FOLLOW-UP

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WITH the ever-increasing use of mass roentgenogram surveys of the chest, appreciable numbers of asymptomatic tumors are being detected. A not uncommon diagnosis is neurogenic tumor of the posterior mediastinum for which excision is usually recommended.

The following case, which was diagnosed as a neurofibroma of the posterior mediastinum, turned out to be an intrathoracic meningocele. The patient has been followed for three and one-half years after operation.

CASE REPORT

E. F., a 31-year-old white woman, following a chest survey which had been done at the cotton mill where she worked, was told to see her doctor, since a tumor was seen on a roentgenogram.

On close questioning, the only symptom admitted was "occasional stiffness of the neck" which was mild. In addition she stated that she had had two roentgenograms of her chest previously in Army surveys while she was employed as a civilian helper in an army air depot, once in 1944 and once in 1945 (two and three years previously). She had never been notified that anything abnormal had been found. Those roentgenogram or reports could not be obtained.

Past History.—Childhood: measles and mumps. Ever since birth small skin growths had been present almost all over the body. One maternal aunt and one paternal aunt had had similar lesions all their lives. The patient had no children. In 1939 appendix and "tumor of ovaries" were removed.

Examination.—(July 2, 1947.) The skin exhibited a typical picture of disseminated neurofibromatosis (Von Recklinghausen's disease). *Head:* The eyes were examined with particular reference to any degree of Horner's syndrome, but were entirely negative. Nothing else of note. *Neck:* Slightly deviated to patient's right. *Chest:* Slight dullness at the left apex with somewhat diminished breath sounds in this region. Heart was normal, blood pressure 110/70, left arm: 105/65, right arm. Vital capacity was 3.8 liters. *Abdomen:* Liver and spleen were not palpable. No masses or tenderness were present. *Extremities:* No neurologic findings of any kind in upper or lower extremities were found. There was no clubbing. *Laboratory:* Blood and urine examinations were normal. *Roentgenogram:* See Figs. 1 and 2.

Homogeneous density was present at the apex of the left chest, merging with mediastinum and revealing a sharply defined outer border. The lesion extended to the level of the sixth interspace posteriorly. Lateral films showed it to fill the whole apical region. Films for better bone definition (see Figs. 3 and 4) showed angular scoliosis with bony deformities of the seventh cervical and first thoracic vertebrae. The left halves of the seventh cervical and first thoracic vertebrae appeared to be narrowed or compressed. In retrospect, this area probably represents bone defect and/or widening of the foramina.

Fluoroscopy: Large dense mass was present filling the whole left apical region. Lower outline was sharp, with no pulsation. There was no change in outline on cough or straining. No shift of mediastinum on forced expiration was noted. The diaphragm moved well.

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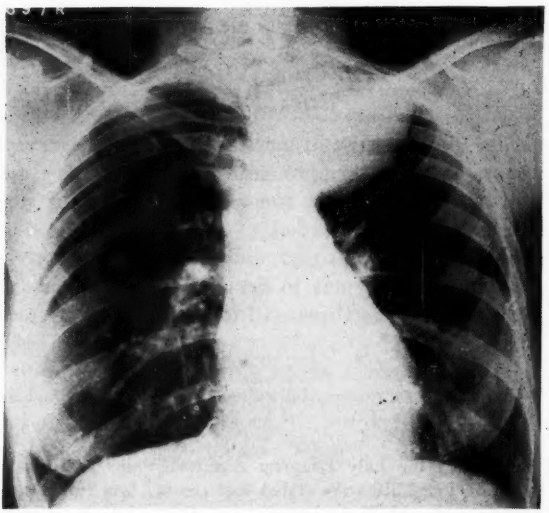

Fig. 1.—Standard chest plate showing large density at left apex with sharply demarcated curved inferior border.

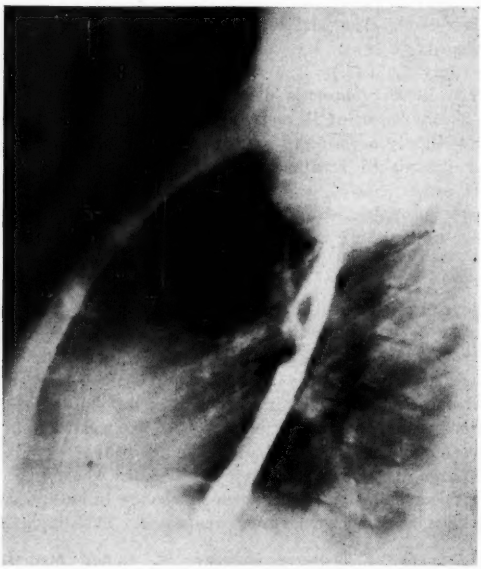

Fig. 2.—Lateral exposure with barium in esophagus. Lesion occupies whole apical region.

Fig. 3.

Fig. 4.

Figs. 3 and 4.—Bony deformities; bodies of seventh cervical and first thoracic vertebrae, compressed or collapsed in left lateral half, slight angular scoliosis, narrowing of posterior segment of second rib.

Preoperative Diagnosis.—(1) Multiple neurofibromatosis with large neurofibroma of posterior mediastinum (possible dumbbell type). (2) Bony deformities of the seventh cervical and first thoracic vertebrae, secondary to (1).

Operation was performed on July 16, 1947, at the Utica Memorial Hospital.

Description of Operation.—Under endotracheal cyclopropane anesthesia a high left posterolateral transpleural approach was used.

The fifth rib was removed subperiosteally from its angle to about the anterior axillary line. The pleura was entered through the bed of the resected fifth rib. The tumor appeared to occupy the whole apical region, and the lung was adherent to the entire lower aspect of the tumor. By combined blunt and sharp dissection, the lung was peeled away from the mass. This was done extrapleurally, as the lung was adherent to the parietal pleura overlying the mass.

During the liberation of the mass, it was noted that it was soft and fluctuant. Ten cubic centimeters of crystal-clear fluid were freely aspirated and, since it was suspected that this might be spinal fluid, it was saved for examination. It was decided to aspirate more of the fluid so as partially to collapse the sac and give better access to the pedicle.

About 120 c.c. of crystal-clear fluid were slowly withdrawn with no untoward reaction.

With the sac partially collapsed, the pedicle was easily approach, and could be felt to be coming from a bone defect in the anterolateral aspect of the vertebral column in the region of what we judged to be the first and second thoracic vertebrae. Two fingers could be placed just within the defect, the long axis being parallel to the long axis of the vertebral column. A double ligature of No. 1 chromic catgut was placed around the pedicle and drawn down tight at the base where it came out of the defect of the vertebral column.

The sac was cut off, leaving a liberal central stump to use in repair. Inspection revealed a slight leak of fluid just proximal to the ligature where there seemed to be a small tear. This was carefully repaired with No. 00 chromic catgut on an atraumatic needle. The defect was strengthened by suturing some pieces of parietal pleura over it after several sutures had been taken from the stump of the ligated sac to the near-by periosteum. Finally, strips of oxycel were laid over the whole area. Usual layer closure was done.

Comment: The sac contained at least 200 c.c. of crystal-clear fluid, and it was tough and resistant though thin.

Postoperative Course.—The patient did very well She was watched closely for any signs of leakage of spinal fluid, but at no time did she complain of headache or other unusual symptoms As a precaution she was kept in a lying position for the first twenty-four hours and then raised to a semisitting position She was ambulant on the third postoperative day.

A Horner's syndrome was noted postoperatively. Within about one week the temperature changes had become mild but the eye findings remained.

Analysis of the specimen of fluid removed from the sac was as follows:

Specific gravity	1.004
Sugar	96
Chlorides	720
Total proteins	43.6
Cells	None

One of the fleshy skin tumors removed from the back at the end of the operation showed it to be a neurofibroma.

The microscopic examination of the sac was compatible with that of dura with some nerve fibers attached on the outer aspect.

Final Diagnosis.—(1) Intrathoracic meningocele; (2) congenital bony defects of bodies and foramina of the seventh cervical and first thoracic vertebrae, with herniation of dural sac; (3) multiple neurofibromatosis.

Follow-Up.—The patient was last examined on Mar. 14, 1951. She presented no complaints. A Horner's syndrome of moderate degree was still present. The last roentgenogram (see Fig. 5) showed no evidence of recurrence.

PREVIOUS REPORTS

At the time of operation, July 2, 1947, we had never heard of such a finding in the chest, and postoperatively we were quite uneasy as to whether excision of the sac had been the correct procedure or whether it would have been wiser to have backed out without disturbing it after the nature of the lesion was apparent.

At that time the only reports of similarly operated cases which we could obtain were those of Pohl,[1] in 1933, of which we were able to get an abstract in English, and of Ameuille and associates.[2] It is of interest that Pohl's patient also had neurofibromatosis, and that the preoperative diagnosis was intrathoracic neuro-

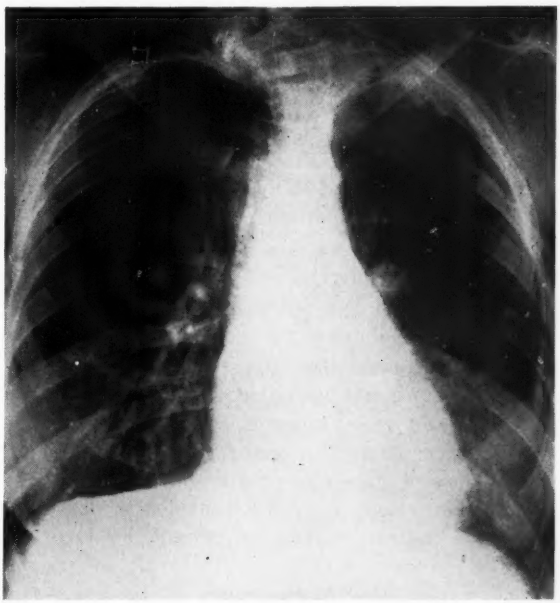

Fig. 5.—Last film over three and one-half years after surgery, showing no evidence of recurrence.

fibroma. The chest lesion had been detected on an x-ray examination taken because of persistent cough following a mild attack of grippe. The patient, a woman, was operated upon, the sac excised, and a strip of muscle was used to cover the defect in the bone and the exposed spinal cord. However, postoperatively she developed an empyema which caused her death.

The case described by Ameuille, Wilmoth, and Kudelski[2] is of marked interest since the patient had had an x-ray examination eleven years previously, preoperative thoracoscopy was done, and a detailed autopsy description of the lesion is also given. Their patient was a 48-year-old woman, who for five years had complained of headaches, mild malaise, and weakness, and was considered a psychoneurotic.

In 1929 Duval had done an Albee graft because of lumbodorsal pain associated with kyphoscoliosis. X-ray study on her recent admission (1940) revealed a rounded shadow at the right base with well-defined borders, about 8 cm. in diameter. The lateral view placed it posteriorly and showed a rounded area of rarefaction in the body of the ninth thoracic vertebra. Artificial pneumothorax was done, and a thoracoscopic examination revealed what was thought to be a hydatid cyst.

Operation was performed, using a transpleural posterolateral route. The sac was easily detached from the right side of the spine, and at that time a punched-out opening was noted on the lateral aspect of the eighth and ninth thoracic vertebrae. "As it is not possible to close the openings in the vertebrae with the pleura, one simply dries the right hemithorax; the parietal pleura is sutured hermetically with all the parietal layers." The patient died on the eighth day with signs of meningitis and pleural exudate infected with *Staphylococcus aureus.*

The authors felt, in retrospect, that if the preoperative diagnosis had been made they could have emptied the sac and then used it, at least temporarily, to close the vertebral openings and so avoid the leakage of spinal fluid which they felt led to the death of their patient.

The next surgical cases that we became acquainted with were three which were presented in a paper by Byron and co-workers[3] at the meeting of the American Association for Thoracic Surgery in May, 1948. Several discussers also presented cases. The published paper will be referred to later.

Shortly after this, we found the report of Welch, Ettinger, and Hecht.[4] They reviewed the literature and presented a successful operative case of their own. In their search, only three reported cases of intrathoracic meningocele were found, two of them being the cases of Pohl and Ameuille, previously mentioned above. These writers also pointed out that their own, and two of the three reported cases, occurred in individuals with neurofibromatosis. At operation they excised the sac at the neck, closed the dura with interrupted silk, and covered the defect with a pedicle graft of the intrinsic dorsal musculature which was sutured to the edges of the intervertebral foramen. Their patient was a woman aged 41 years.

The next reported surgical case was that of Mendelsohn and Kay.[5] Once more the preoperative diagnosis was neurofibroma, in a woman patient with generalized neurofibromatosis. At operation the sac was opened widely, and the defect in the subarachnoid space was closed by imbricating the cyst wall and the parietal pleura with interrupted silk sutures. A small amount of talc was sprinkled over the pleura in this area to promote fibrosis. Roentgenograms "nine days and one month after the operation showed a complete recurrence. X-ray pictures one year later showed a complete regression, and the patient continues to be well except for low back pain with sciatic radiation suggestive of herniated vertebral disc." The patient refused further study.

Mendelsohn and Kay also pointed out the association with neurofibromatosis, and noted the high incidence in women. They referred to a personal

communication with S. O. Freedlander, in which the latter stated that he had operated on a middle-aged woman with cutaneous neurofibromatosis who had a meningocele projecting into the posterior mediastinum. Kay observed an intrathoracic meningocele as an incidental finding at the autopsy table, but no mention was made of sex or the presence of neurofibromatosis.

The last published report is the complete paper by Byron, Alling, and Samson[3] which, as stated above, had been read in May, 1948, at the meeting of the American Association for Thoracic Surgery. They review the literature thoroughly, and the reader is referred to their article for the bibliography and further details of previously reported cases with the exception of those of Welch and associates, and Mendelsohn and Kay. Byron and co-workers operated on three patients, again with a preoperative diagnosis of neurofibroma of the mediastinum. One male patient had neurofibromatosis with *café au lait* spots, and another patient had *café au lait* spots but no neurofibromatosis. Bony changes of the vertebral column and ribs were present in two of the individuals.

Their first patient was treated by utilizing a portion of the cyst wall or dura as a flap to close the defect. This was then covered by a free pleural graft and a layer of Gelfoam. Postoperatively the patient experienced mild intermittent headache, but did well, and continued so after discharge. In their second patient no effort was made to treat the sac found at operation. The diagnosis of meningocele was confirmed by injection of Pantopaque into the sac and then visualizing it in the spinal canal. In their third case, a 61-year-old man, the cyst extended high into the neck, being embedded in the lower roots of the brachial plexus, making the exposure very difficult and resulting in considerable bleeding. Cardiac arrest occurred with no response to massage, etc.

In their review of previous cases, they mention the patient of Pohl, who died of empyema and meningitis; the patient of Ameuille and associates, who also died postoperatively of empyema and meningitis; a case reported by Schuller and Uiberall[6] diagnosed by myelography.

In the discussion of the paper of Byron and associates, Jerome Head reported an additional case in a 43-year-old man on whom a routine film of the chest revealed a globular tumor adjacent to the spine. Simultaneous puncture of the tumor and spinal canal revealed that withdrawing fluid from the tumor lowered the pressure in the spinal canal, and withdrawing fluid from the spinal canal lowered the pressure in the tumor. Examination of the specimens showed them to be comparable in appearance, cell count, and chemical analyses. Diagnosis of intrathoracic meningocele was made, and the patient was not operated upon.

DISCUSSION

Surgical Indications.—From the surgical viewpoint the important question is—if this lesion is diagnosed preoperatively or encountered at thoracotomy, should it be attacked surgically or left alone?

Welch and collaborators apparently feel that surgery is warranted, but Mendelsohn and Kay state, "We are in doubt as to the advisability of operating

on this type of lesion unless it shows progressive enlargement or causes symptoms. The defect is difficult to repair satisfactorily and might be associated with a high incidence of recurrence. It is felt that this is an innocuous tumor which is difficult to cure surgically, and that surgical interference is not indicated if the patient is asymptomatic."

Byron and associates were of the opinion that "in patients with relatively small sacs, operation is probably not justified unless serial chest roentgenograms reveal progressive enlargement to the point of progressive respiratory embarrassment." In the discussion of his paper Byron stated, "I think there is some importance in making a preoperative diagnosis, because I do not believe operation is indicated in all cases. In the first place with a large bony defect, it is questionable in many cases whether the defect can ever be satisfactorily closed, and, second, since I believe that the meningocele is a herniation of the dura, I see no reason why herniation cannot recur."

To the writer it seems reasonable enough to assume that surgery is indicated in a patient having symptoms. It also appears logical to defer surgery and follow the patient roentgenologically if the diagnosis is made preoperatively and the patient is asymptomatic. If the sac shows progression it would seem advisable to operate early to avoid technical difficulties which are greater in the large-sized sacs with marked bony erosion.

However, if the lesion is undiagnosed and encountered at thoracotomy, we feel that it should be treated surgically and not left alone. This attitude appears justified because a study of the reported cases and our own points to the fact that this is a *progressive* lesion. In our patient two previous survey films were supposedly negative, the last one approximately two years before the time of diagnosis. It may be assumed that the lesion must have been much smaller to have been missed even on a small film.

In the case of Ameuille and associates, the lesion had progressed and caused marked bony erosion within a period of eleven years, since on x-ray examination in 1929 the sac was not seen, whereas in 1940 the sac was 8 cm. in diameter and there was extensive bone erosion. In Case 1 of the report of Byron and co-workers, there had been progressive enlargement of the sac over a period of about five years from a 10 cm. diameter to a size where the sac occupied two-thirds of the hemithorax. The common occurrence of erosive bone changes in the reported cases is additional evidence of the progressive nature of this lesion.

Therefore, it is felt that if this lesion is encountered at thoracotomy there should be no hesitancy in treating it surgically by the method appropriate to the individual case. In the cases treated surgically in the present era of thoracic surgery, the early results have been good. The first surgical patient, who was operated upon prior to the present development of intrathoracic surgery, died as a result of empyema and meningitis. The other case which ended in a similar fashion was done in 1940, *but no attempt was made to close the dural defect,* and, in view of this, it is difficult to see how the result could have been otherwise. The remainder of the cases treated by direct surgical treat-

ment of the lesion number five, including our own case. One 61-year-old poor-risk patient died on the table. The other four have shown early favorable results. Obviously the late results, after a period of years to determine the presence of recurrence, will have to be considered before final evaluation of the treatment can be made.

However, with the use of additional aids in closure of the defect when indicated, such as fascia lata, nonreactive polyethylene, absorbable cellulose, grafts, and other modern aids, it seems that a permanent successful result should be obtained.

We have purposely delayed reporting our own case in order to have more than a short postoperative follow-up. At the time of writing, three and one-half years postoperatively, there is no evidence of any recurrence.

Preoperative Diagnosis.—When the possibility is suspected, as in a patient with neurofibromatosis, confirmation may be obtained by instillation of radiopaque substance into the spinal canal followed by posturing in an attempt to get the opaque material into the sac and then to demonstrate it roentgenologically. Or the reverse may be done, as demonstrated in one of the cases reported by Byron and associates, in which opaque material was instilled into the sac by direct puncture through the thorax and then made to enter the spinal canal.

Institution of pneumothorax with thoracoscopic visualization, palpation with a rod for consistence, etc., as reported by Ameuille and co-workers, might be done. To this one could add direct thoracoscopic puncture with analysis of the fluid.

Puncture through the thoracic wall is simple and practical, except for the natural reluctance to do this in the presence of a "tumor mass" of unknown nature.

It is felt that the exact preoperative diagnosis of this lesion may not be of such great importance; if there were no contraindication to operation on the basis of a diagnosis of neurofibroma of the mediastinum, it is felt that the same thinking may apply in the case of meningocele, especially if one subscribes to the view that this tends to be a progressive lesion.

CONCLUSIONS

It is recommended that if encountered at thoracotomy a meningocele should be treated surgically, since the evidence points to the premise that this is a progressive lesion. If the diagnosis is made preoperatively in a patient with symptoms it is felt that surgery is indicated. If asymptomatic, extended roentgenogram observation over a period of years may be used to determine the advisability of surgery.

The surgical treatment should include meticulous closure of the dura. This closure and that of the bony defect should be supported by whatever means possible—parietal pleura, muscle flap, fascia lata, nonreactive polythene, etc.

Four operative cases, including the author's, reported in the American literature, which were done in the era of the present development of chest surgery, have shown early favorable results. In a fifth a mortality occurred

during surgery in a poor-risk patient. Two cases reported in the European literature, done at an earlier period, died of infection with meningitis. This brings the total of patients subjected to direct surgical attack of the lesion to seven.

SUMMARY

1. A case of successful excision of an intrathoracic meningocele is presented. There has been no recurrence during a three and a half year follow-up.

2. Previous surgically treated cases are reviewed and discussed. These number six, the author's case bringing the total to seven.

3. The preoperative diagnosis, surgical indications, and surgical treatment are reviewed.

4. It is felt that this is a progressive lesion and that, in general, surgery is indicated.

ADDENDUM

Since this paper was written the patient has been seen again and continues to do well with no roentgenographic evidence of recurrence.

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LACERATION OF THE AORTA

Case Report of Successful Repair Forty-eight Hours After Injury

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Washington, D. C.

STAB wounds of the great vessels are usually fatal. Bradford and Johnston reviewed the world's literature in 1950, and found that ninety cases of traumatic rupture of the aorta had been reported. Only seven of the ninety patients lived more than eighteen hours from the injury. Only four patients survived. In all four of these patients the laceration of the aorta had occurred inside the pericardium. No patient with laceration of the aorta outside the pericardium survived. However, Bradford and Johnston described a patient of their own who sustained a traumatic rupture of the aorta just proximal to the diaphragm. Five weeks after the original injury, which broke several ribs in the right thorax, the patient suddenly went into shock and was found to have a hemothorax on the right side. When a right thoracotomy was done about eleven weeks after the injury, profuse bleeding was encountered. The bleeding could be controlled only with packing. A second thoracotomy on the right side eighty-one days after injury disclosed the true diagnosis, but not soon enough to save the life of the patient who died on that day. However, the authors felt that there was no way to save the patient. The lesion was inoperable from the right side, and a left thoracotomy would not have been tolerated with such a large right hemothorax.

The first successful closure of a laceration of the aorta was performed by Dshanelidze of Russia in 1922. The patient was a 22-year-old man who received an 8 mm. laceration of the aorta 1 cm. above the heart. No mention was made of the weapon used nor of the time that elapsed before the laceration was closed.

The second case was reported by Blalock in 1932. His patient was an 18-year-old man stabbed with an ice pick about forty-five minutes before admission to the hospital. The size of the laceration was not stated.

The third case was reported by Elkin in 1941. The patient was a 28-year-old woman who was stabbed with an ice pick a few minutes before admission to the hospital. The size of the laceration was not stated.

The fourth case was reported by Elkin in 1944. The patient was a 44-year-old man who was stabbed in the chest with a knife. The patient came to the hospital immediately and was operated upon sixty minutes after admission to the hospital. There was no mention of the size of the laceration.

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CASE REPORT

A 21-year-old Negro man walked into the Emergency Room of the Gallinger Municipal Hospital at 1:15 A.M., Oct. 31, 1950, with the complaint that he had been stabbed in the chest with a penknife four and one-half hours before. He stated that there had been a moderate amount of bleeding from the wound, that he was slightly short of breath, and that he had pain anteriorly in his left chest on inspiration.

Family history was noncontributory except that his grandfather had had a history of convulsive seizures.

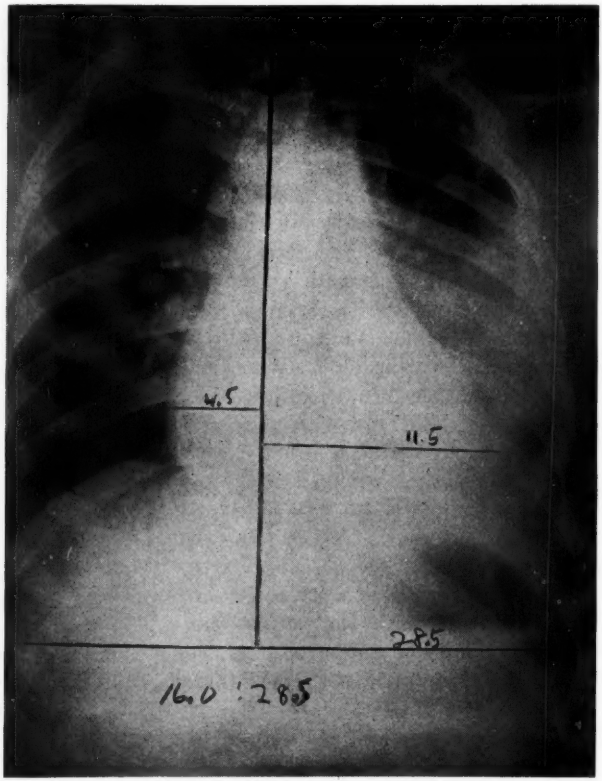

Fig. 14.—Posteroanterior chest roentgenogram taken at the time of admission to the Emergency Room. The knife blade in the mediastinum can be faintly seen.

Past history was noncontributory other than that the patient had had a skull fracture at the age of 5 years.

Physical examination showed a young Negro man who was moderately dyspneic and uncooperative, but who did not appear to be more than moderately ill. His temperature was 98.6° F. by mouth, pulse rate 100, and respiratory rate 24. The blood pressure in his right arm was 200/120. There was a 2 cm. laceration over the second interspace about 1 cm. to the left of the sternum. The wound bled very slightly. Breath sounds were bilaterally equal and normal. The heart sounds were of good quality, with a short, soft apical systolic murmur. No friction rub was heard. The radial arterial pulse was full and regular.

The remainder of the physical examination was within normal limits.

Laboratory data: The hematocrit was 33 and the hemoglobin was 71 per cent. The white blood cell count, the urinalysis, and the serology were normal.

Hospital course: A roentgenogram of the chest was made. Wet reading of the film was thought to be within normal limits. The laceration in the skin was sutured, 1,500 units of tetanus antitoxin were administered in the Emergency Room, and the patient was admitted to the hospital on the George Washington Surgical Service.

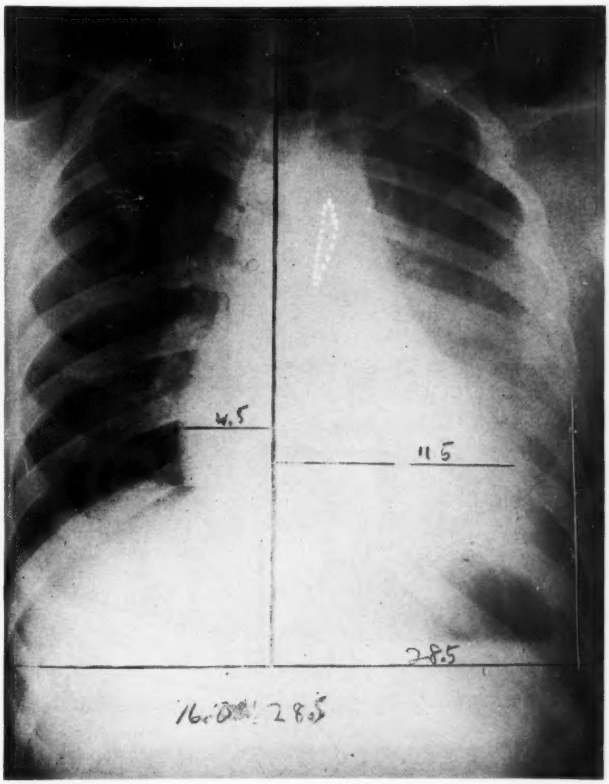

Fig. 1*B*.—This is the same roentgenogram as Fig. 1, but the knife blade has been outlined.

Twelve hours after the injury, the patient had a grand mal seizure. He lost consciousness, had a generalized convulsion, and was incontinent. After this episode, which lasted about two minutes, the patient was drowsy. He was slightly cyanotic after the convulsion, and oxygen administration was started. The neurologic examination was within normal limits but for hypoactive reflexes. The neurologist felt that anoxia had brought latent epilepsy into a grand mal seizure.

The chest roentgenogram taken in the Emergency Room was temporarily misplaced, but it was found several days later. See Figs. 1*A* and *B*. A second chest film was taken thirty-six hours after the injury. This film showed an enlarged cardiac silhouette and a knife blade in the mediastinum. No lateral chest film was taken.

About forty-four hours after the original injury the patient became cyanotic and orthopneic. His blood pressure fell to 70/50. The pulse rate was 140, and it was paradoxical in character. The neck veins were distended. The heart sounds were audible and seemed relatively normal. The liver edge was three fingerbreadths below the costal margin, and the venous pressure was 190 millimeters of saline.

A diagnosis of cardiac tamponade was made, and the patient was prepared for operation.

Approximately forty-five hours after the injury, while preparations for operation were being made, the patient became unconscious and his blood pressure could not be measured. After 30 c.c. of blood were aspirated from the pericardium, he regained consciousness. His blood pressure was then 120/80 and his pulse rate was 120. The patient was still cyanotic and dyspneic.

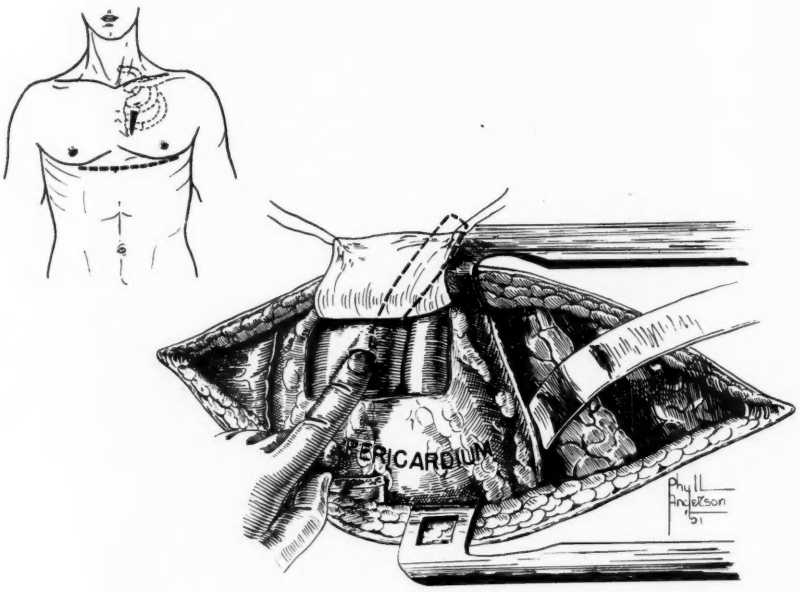

Fig. 2.—A drawing of the operative incision and the appearance of the laceration in the aorta.

Operation: The operation was begun nearly forty-eight hours after the injury with pentothal and endotracheal ether anesthesia, and the left chest was opened anteriorly by resecting the left fifth rib from the sternum to the posterior axillary line. About 500 c.c. of blood were removed from the left pleural cavity, but the lung was entirely normal. The anterior mediastinum was hemorrhagic and edematous. Inspection of the heart showed marked muffling of the heartbeat. The incision was carried across the sternum, and the right fifth interspace was incised intercostally for approximately four inches. The pericardium was opened transversely. A thin layer of blood was found to tamponade the heart. Just after the pericardium was opened, bright red blood gushed out from the upper pericardial sac. Immediate digital palpation along the anterior surface of the ascending aorta revealed a laceration about 14 mm. long just inside the superior pericardial attachment. (See Fig. 2.) Hemostasis was maintained with the palpating finger. Each time the patient breathed the

point of the knife blade struck the back of the finger compressing the laceration. The aorta was compressed dorsally, the tip of the knife blade was grasped with an instrument, and the blade was withdrawn. It was later found to be 6 cm. in length.

To gain exposure the pericardium was incised in a cephalad direction at each end of the transverse incision, and a pericardial flap was turned upward. Five interrupted 0000 atraumatic silk sutures were used to close the laceration. The left pleural cavity was drained with an intercostal catheter, and the chest was closed in layers with interrupted silk sutures.

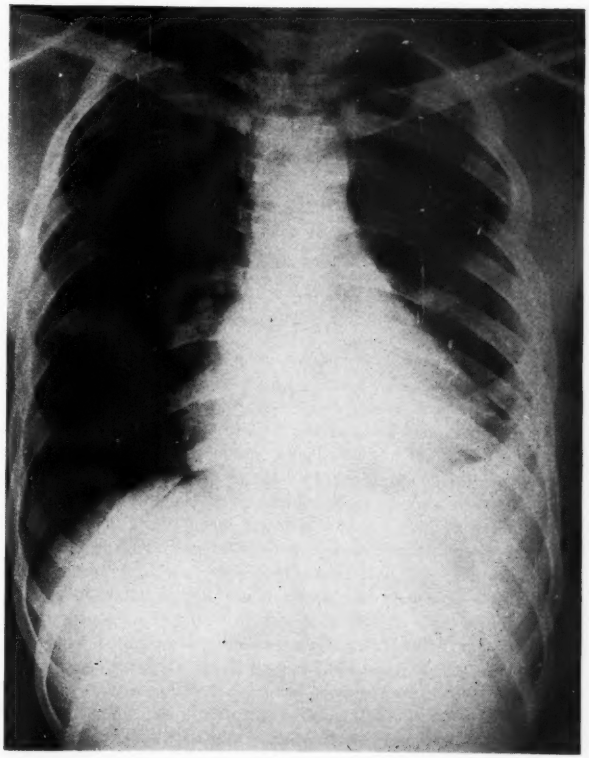

Fig. 3.—A chest roentgenogram taken fourteen days after the operation.

During the operation the blood pressure was at all times above 120 mm. Hg systolic. The blood pressure at the conclusion of the operation was 155/95. The patient received 1,800 c.c. of whole blood and 1,000 c.c. of dextrose solution intravenously during the operation.

Postoperative course: The patient was given an additional 500 c.c. of whole blood on the first postoperative day. Penicillin was administered for seven days. On the eighth postoperative day the blood pressure was 118/66. He was discharged to his home on the eighteenth postoperative day (Fig. 3). Three months after the operation the patient was alive and well.

SUMMARY

A case has been presented in which a knife blade 6 cm. long was removed from the anterior mediastinum forty-eight hours after injury. A laceration of the ascending aorta inside the pericardium was successfully closed. This is the fifth successful repair of a lacerated aorta.

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ARTERIOVENOUS FISTULA OF THE AORTIC ARCH

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IN NOVEMBER, 1950, Proctor[1] reported the first case of arteriovenous fistula of the aortic arch. This fistula was due to trauma and was successfully repaired.

We have recently had the opportunity to treat a patient with a traumatic arteriovenous aneurysm between the aortic arch and the left innominate vein. In this case the aorta and the vein were not in contact, and there was a definite false sac interposed between the two structures.

As the patient was treated on the same service for the original stab wound which produced the fistula, we had the opportunity to see the heart enlarge due to the effect of the fistula, and then return to normal size after closure. We feel that too long an interval occurred between the onset of the fistula and its closure, but that we were fortunate in getting her to surgery before evidence of cardiac failure appeared.

CASE REPORT

A 25-year-old Negro woman was admitted to the Shreveport Charity Hospital on Nov. 16, 1949, having been stabbed several minutes before admission. She was in deep shock, with little evidence of external bleeding. There was a 1 cm. stab wound over the left sternoclavicular joint, and several small stab and incised wounds of the arms.

Following a transfusion of 1,000 c.c. of blood, her blood pressure rose to 118/70, although her pulse remained around 120. The next day a continuous murmur with systolic accentuation was heard over the entire chest, being more marked over the aortic area. During the next few days the murmur became louder and a palpable thrill appeared. On Nov. 18, 1949, chest roentgenogram showed a homogeneous density involving the superior mediastinum. The roentgenogram was repeated on Dec. 2, 1949, and showed some resolution of the mediastinal shadow, but the mediastinum was still widened, and there was a definite border extending to the left of the manubrium. An electrocardiogram on Nov. 22, 1949, showed sinus tachycardia. Sound tracings revealed a continuous murmur, with systolic accentuation, appearing to be of greatest intensity on the medial side of the wound. Next in intensity was the area on the lateral side of the wound, with the inferior area being next in intensity, and the superior area being least in intensity. Blood pressure was equal in both arms on several occasions. One venous pressure determination showed a pressure of 110 mm. of water in the left ante-cubital vein, and 140 mm. in the right ante-cubital vein. At this time, however, the right arm was somewhat swollen and edematous due to reaction around its laceration. She ran a febrile course spiking to 100° F. for one week, and then became afebrile. At the time of her discharge on Dec. 5, 1949, she was asymptomatic except for consciousness of the murmur and thrill.

On her return admission on Jan. 1, 1950, the electrocardiogram was normal, the rate being seventy-five per minute. Roentgenogram of the chest showed almost complete resolution of the superior mediastinal shadow. There was some increase in the size of the heart. The loud, machinelike murmur with systolic accentuation was still present, as was the thrill. She was discharged to the clinic on Jan. 9, 1950, to be admitted for surgical correction of the fistula within three or four months.

From the Thoracic Surgical Service, Shreveport Charity Hospital.
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She was readmitted, having been lost to follow-up in the meantime, on Nov. 24, 1950, with no symptoms other than an awareness of the thrill, of which she was constantly conscious. Blood pressure on admission was 106/50 in the right arm, and 112/60 in the left. The murmur was loud and heard all over the chest and back, but was loudest over the manubrial area. The palpable thrill was also more noticeable over this area. Roentgenogram of the chest showed some widening of the superior mediastinum and a definite cardiac enlargement, confirmed by fluoroscopy, since the last admission. Electrocardiogram was within normal limits.

The operation was carried out Dec. 3, 1950. The incision described by Shumacker[2] was used, and gave excellent exposure. The incision started at the middle of the left clavicle, curved down over the left sternoclavicular joint, and extended down to the midsternum. The veins of the anterior chest wall and neck were extremely dilated. The

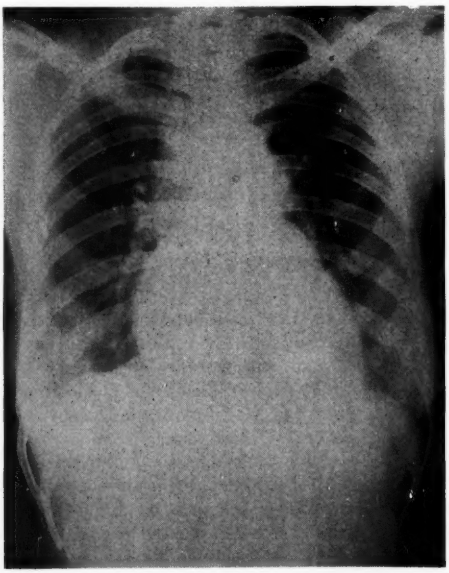

Fig. 1.—Roentgenogram taken on Nov. 27, 1950, immediately preceding the operation. Note superior mediastinal shadow and enlarged heart.

inner one-half of the left clavicle was resected subperiosteally and the attachments of the sternomastoid, sternohyoid, and the sternothyroid muscles were sectioned. This exposed a tremendously dilated innomonate vein through whose wall blood could be seen whirling in eddies. The retrosternal space was entered with difficulty because of previous reaction and the presence of a pulsating mass beneath it.

It was necessary to split the sternum considerably to the right of the midline to avoid this mass. The sternum was split down to the third interspace with the Lebsche Sternum Knife, and then cut through on each side. The left part was elevated with bone hooks and separated from the underlying mass by sharp dissection. A small rib spreader then gave excellent exposure.

A pulsating, thick-walled mass about 8 cm. in diameter occupied the entire retrosternal space. The dilated left innominate vein crossed superior to this mass and was firmly attached at this point. Pressure with the finger here stopped the visible flow of arterial blood into the vein. The vein was dissected free and rubber dam drains placed around it, both proximal and distal to its communication with the sac.

The sac was then dissected free with considerable difficulty, but there was no significant bleeding. It was necessary to mobilize, but not remove, the thymus, and dissect off both anterior pleural reflections. Neither pleural cavity was entered. The sac was completely mobilized and was found to communicate with the aorta on its anterior-superior surface, about 2 cm. distal to the origin of the innominate artery.

Fortunately the sac narrowed at this communication and connected to the aotra by a neck about 3 cm. in length and 2 cm. in diameter. A rubber drain was passed around the aortic communication and it was occluded. This stopped the thrill and had no effect on the pulse of either arm or either cartoid artery. The rubber drains around the vein were then occluded and the aneurysm opened and emptied. There was no bleeding.

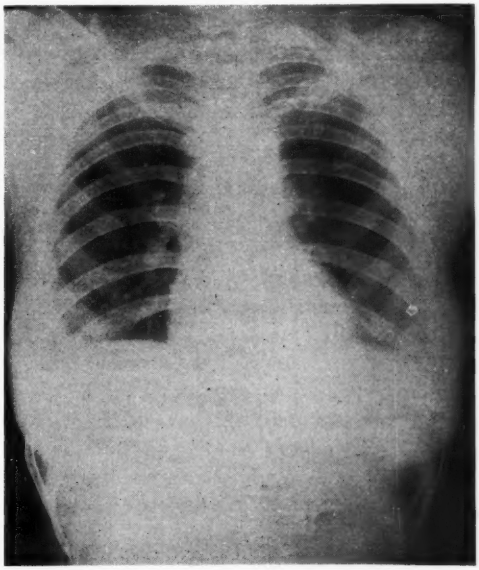

Fig. 2.—Roentgenogram taken on March 9, 1951. Note absence of superior mediastinal shadow, decrease in heart size, and regenerating left clavicle.

The opening into the innominate vein was about 2 cm. long and slitlike. While feasible, suture of this opening did not appear necessary, so the innominate vein was ligated and suture ligated on each side of the communication and severed, leaving a small segment attached to the sac. The sac was then elevated and the aortic communication ligated with No. 2 braided silk flush with the aortic wall. A suture ligature of the same material was placed distal to the ligature and the sac completely excised. The aortic communication was further closed with interrupted No. 00 cotton sutures. The sternum was brought together with periosteal sutures, and the wound closed, placing bone chips in the bed of the resected clavicle.

Five hundred cubic centimeters of blood were given during the operation.

The postoperative course was relatively uneventful, except for a febrile reaction to 102° F. on the first postoperative day. This gradually subsided, the wound healed well, and she was discharged Dec. 17, 1950, on her twelfth postoperative day.

When last seen on March 9, 1951, she was asymptomatic, no murmur was present, arm and shoulder functions were excellent, and she had resumed work. Roentgenogram of the chest at this time showed no discernible widening of the mediastinum, beginning regeneration of the clavicle, and a heart that had returned to normal size.

CONCLUSION

1. The second case of arteriovenous fistula of the aortic arch is presented.
2. This has apparently been cured by the removal of a false aneurysmal sac between the arch of the aorta and the left innominate vein.

ADDENDUM

This patient was seen June 12, 1951. At this time she was asymptomatic, and no murmur or thrill was present. Roentgenogram of the chest was within normal limits. Clinically there was firm regeneration of the clavicle and arm function was excellent.

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AN EXPERIMENTAL EVALUATION OF CATGUT AS A VASCULAR SUTURE MATERIAL AND A REPORT ON ITS CLINICAL USE

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CERTAIN developments occurring during little more than the past decade have caused what might be considered the renaissance of vascular surgery. The great success enjoyed in the extension of surgical treatment of congenital anomalies of the heart and great vessels, and in the care of vascular injuries of World War II, have stimulated laboratory studies to the extent that nearly all centers of medical research are now pursuing one or more major projects related to vascular surgery.

As might be expected, certain of the time-honored and traditional rules governing vascular surgical technique, as evolved at the beginning of the century, have been greatly modified. The advent of anticoagulant and antimicrobial drugs, the development of large blood banks, and the use of intra-arterial transfusion have been major factors in this metamorphosis.

Opposition to the use of catgut as a vascular suture developed in the early years when infection, thrombosis, and hemorrhage were common complications of major vascular surgery. This seems to be almost a paradox, since catgut was the standard suture material of the time, and only a few pioneer surgeons such as Kocher[1, 2] and Halsted[3, 4] were showing real interest in silk thread. While subsequent years saw a slow, steady shift in favor of fine, nonabsorbable suture material, the use of fine silk in vascular surgery had long been firmly established.

Although the controversy of silk versus catgut continued to rage in general surgery (Halsted,[3-4] Haegler,[5] Heidenhain,[6] Howes,[7-11] Whipple,[12] Elkin,[13] Bower and Pearce,[14] and Gage and Lyons[15]) there appeared to be no disagreement among vascular surgeons as to the superiority of silk. However, as increasing numbers of children were operated upon for coarctation of the aorta, tetralogy of Fallot, and portal hypertension where growth at the site of anastomosis commensurate with that of the individual would be desirable, experimental studies have appeared, reporting the relative value of various techniques of vascular suture and kinds of suture material, especially in the growing animal.[16-22a] It was shown by certain investigators that fine chromic catgut was a more satisfactory vascular suture material than silk when used as a continuous suture in a growing animal.[18, 19, 20] These observations were derived, however, from the study of single anastomoses in the repair of the aorta of dogs and pigs. We considered it possible to obtain a better comparison of vascular healing, if

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chromic catgut and silk were used in the same animal for the vascular anastomoses. By implantation of carotid and aortic grafts, the suture material could be studied when used with viable and nonviable grafts and in vessels of varying size. The anastomosis of a nonviable homograft to an adjacent normal vessel under tension should impose a significant stress on a suture material.

METHODS

A total of twenty dogs were used in this study. One group of twelve adult mongrel dogs were used to study the suture lines of aortic grafts. Of these, eight had implantation of the graft into the abdominal aorta distal to the renal arteries, and four into the descending arch of the thoracic aorta. In all of the operations on the abdominal aorta, a comparable segment of normal aorta was excised before implanting the graft. The grafts measured 1.5 to 3.2 cm. in length and had been stored for periods up to six months (Table I). Only during the implantation of the thoracic grafts was a paraffin-lined glass tube used for temporary restitution of aortic blood flow. The tube was removed just before completion of the distal anterior suture line. By this method, the time during which the aortic blood was halted was two periods of about three minutes each. In none of these dogs nor in any of the others was there any muscular weakness or paraplegia.

A group of eight adult mongrel dogs were used to study anastomosis of carotid grafts. Both arteries were exposed by a vertical incision in the neck. In all instances, a segment 1.5 to 2.9 cm. in length was excised from the mobilized right common carotid artery and implanted into the left common carotid artery, after excision of a segment of comparable length. A carotid homograft measuring about 2.0 cm. and which had been preserved for up to fifteen weeks was then implanted into the defect in the right common carotid.

The proximal and distal anastomoses were accomplished in the carotid vessels by the Carrel technique. In the aorta, an everting continuous horizontal mattress suture was employed. Two single horizontal mattress traction sutures were placed equidistant along the circumference. The posterior row was completed by rotation of the vessel and graft. After running the free suture from one traction suture to the other and tying them together, the vessel was rotated back into normal position and the anterior row completed in a similar manner, using the free end of the second traction suture. In all the grafts nonboilable medium chromic catgut swaged on a one-half circle atraloc taper point needle* was used for the proximal anastomosis. For the inferior or distal anastomosis, braided black silk swaged on a three-eighths circle taper point needle† was employed. For implanting the carotid grafts, we used 000000 suture material, whereas we preferred 00000 for the aortic anastomoses.

Anticoagulant drugs were not given to any of these animals. The function of the graft was checked frequently by evaluation of the peripheral arterial pulses, and at rare intervals by angiography.

When the animals died or were killed, the graft was excised with adjacent host vessel and was opened by an incision in its long axis. The suture line was observed for constriction or thrombosis and for the amount of suture material presenting on the inside of the lumen. Of secondary interest were any degenerative changes or localized thrombi involving the actual graft. Microscopic

*Supplied by Ethicon Suture Laboratories, Inc., Type C 5-0 Code F131; Type C 6-0 Code F130.

†Supplied by J. A. Deknatel & Son, Inc., 5-0 Lot No. 155; 6-0 Lot No. 156.

preparations were made of sagittal sections of the entire graft and adjacent host vessel. Hematoxylin and eosin, Voerhoff's elastic stain and trichrome connective tissue stains were used in all instances.

RESULTS

Technical Evaluation of Suture Material.—It was a unanimous opinion among five vascular surgeons at Presbyterian Hospital testing both sizes of catgut and silk, that the latter seemed easier to handle, although others have felt the reverse to be true.[14] One of us who had previously used catgut extensively in general surgery concurred in this opinion, although the other operators had always used silk as a standard suture material. The gut was stiffer and appeared to dry quickly, especially when used as a traction suture. Furthermore, the tensile strength on occasion appeared to vary in a single strand, with unexpected breakage or fraying occurring while performing an anastomosis.

Fig. 1.—Graft obtained from thoracic aorta and stored in a nutrient electrolyte solution seven days before use in thoracic aorta of another dog. After implantation of one hundred fourteen days, the proximal chromic catgut anastomosis (left) is barely visible, whereas a few silk sutures mark the distal suture line. The white spots are highlights.

Since the usual vascular anastomosis depends upon one suture line, this apparent lack of uniformity gave some concern, and has been noted by others.[22, 23] While we have encountered similar variability in some commercial brands of braided arterial silk, the lots of silk used in this study were very satisfactory in all respects.

Function and Gross Appearance of the Implanted Grafts and Anastomoses.—The eight grafts used in the abdominal aorta had been quick frozen at –72° C. and stored at low temperatures. Four had been kept for from twenty-three to one hundred thirty-five days at –27° C. and four for from twenty-three to ninety days at –70° C. (Table I.) One partial occlusion by a mural thrombus occurred in the former group. In this one, there was a moderate sized pedunculated thrombus originating from the proximal catgut suture line, but it was well endothelized and did not interfere with function significantly. Among

the others, examined from seven to ninety-three days after implantation, three small endothelized mural thrombi were found at necropsy. Function had been excellent in all.

Of the four segments of aorta implanted into the thoracic aorta, one had been quick frozen at –72° C. and stored for one hundred and seventy-eight days at –70° C., whereas the other three had been refrigerated at 4° C. in Simm's X6 solution containing 10 per cent homologous serum for seven, sixteen, and two hundred and four days. In none of these did thrombus formation occur (Fig. 1). With one exception the anastomoses were examined after periods of implantation of over one hundred days.

The carotid autografts implanted in eight dogs retained the gross appearance and physical characteristics of the normal adjacent vessel. In none of the specimens was there any visible degeneration or thrombus after implantation of from sixteen to one hundred and sixty-eight days. It was interesting to note that the minimal fibrous reaction binding the graft to the adjacent tissues of the neck was often of about the same degree observed on the side with the carotid homograft.

Of the eight carotid homografts, four were frozen grafts stored at –70° C. for eighteen to fifty-five days, and four were grafts kept in the nutrient solution for from thirteen to fifty days. In one from each group there was complete occlusion by thrombus formation. In another of the frozen grafts, function was diminished by a thrombus. All of these carotid grafts with thrombosis had been stored six weeks or longer (Table I). The inside diameter was generally about three millimeters. These grafts were examined after from sixteen to one hundred and sixty-eight days of implantation. The homografts of both types were thinner, less elastic, and slightly dilated when compared to the autograft in the opposite carotid artery (Fig. 2) until two to three weeks, after which the wall was thickened by fibroplasia and dilatation appeared diminished.

In no instance was there a dehiscence of the suture line. Two animals had old hematomas adjacent to a carotid graft but no evidence of any source of leakage from either suture line was apparent at the time of operation or autopsy.

The suture lines of the twenty homografts and eight autographs were examined from one day to one hundred and sixty-eight days after anastomosis. The early gross appearance was very comparable, with little or no suture material visible in the lumen. An equivalent minor degree of inflammatory response was noted at both of the suture lines, with endothelization occurring within a few days in all instances. As noted before, sizable thrombi involved the proximal catgut suture line and the homograft in one aorta and three carotid arteries. Three additional abdominal aortic grafts had sessile mural thrombi limited to the mid-portions, several millimeters from either suture line. In none of the autografts was there any thrombus.

At about two weeks, or even less, minimal vertical lengths of catgut or silk suture material were visible under the new endothelium at the line of anastomosis. Little more suture material became visible subsequently in the carotid specimens in which a continuous Carrel technique had been employed (Fig. 2). However, in the aortas, the visible lengths of silk and catgut sutures

beneath the endothelium became greater as the eversion of the cut edges of the vessels produced by the mattress sutures became less (Fig. 3). After three or four months, the eversion is often barely discernible grossly and photomicrographs may show essentially end-to-end healing of the edges of the vessels.[18] As this flattening occurs, the suture material slowly assumes a superficial vertical alignment. As this process develops in the eversion type of anastomosis, lengths of suture material of one to three millimeters may be seen at the site of each stitch. This appearance should not be attributed to faulty suture technique, as has at times been claimed. In this respect, the catgut anastomosis always appeared better than the silk one since the absorbable material often was not grossly visible after several weeks (Fig. 3). Function was equally satisfactory, however.

Fig. 2.—The autograft in the left carotid artery reveals no gross differences from the recipient vessel. The homograft implanted into the right carotid artery after three weeks of storage at −70° C. is slightly thinned and dilated. The suture lines appear very satisfactory, with chromic catgut still intact in the lower anastomoses, twenty-five days after implantation.

Minor constriction at the everted anastomosis was observed in a few instances at the close of operation. Subsequent study of the anastomoses to determine the degree of constriction revealed no constriction in any of the catgut series greater than that observed at operation. After three or four weeks, even this minor constriction had become less evident. This effect coincided with absorption and fragmentation of the catgut suture material. In the silk group of anastomoses, the degree of constriction at three to six weeks was essentially the same as at time of surgery, or slightly greater. Later, however, flat-

TABLE I

TYPE OF GRAFT	DOG NO.	AGE OF GRAFT (DAYS)	LENGTH OF GRAFT	METHOD OF STORAGE (CM.)	DURATION IMPLANTED (DAYS)	FUNCTION	STATUS OF GRAFT EXCISED				CAUSE OF DEATH	WEIGHT OF DOG (KG.)
							THROMBOSIS	EROSION	DILATED	THINNED		
Aortic:												
Abdominal												
Frozen	232	23	2.5	−27° C.	7	Excellent	0	+	+	+	Killed	19.9
	212	64	2.6	−27° C.	12	Excellent	+	0	+	±	Distemper	9.9
	433	135	3.2	−27° C.	12	Good	+*	0	+	+	Killed	12.1
	258	45	2.2	−27° C.	61	Excellent	0	+	0	0	Killed	12.2
	435	35	2.7	−70° C.	7	Excellent	+	0	+	+	Killed	11.1
	476	42	2.6	−70° C.	14	Excellent	+	0	±	±	Killed	13.0
	227	12	1.5	−70° C.	92	Excellent	0	+	0	0	Killed	12.3
	215	48	2.5	−70° C.	93	Excellent	0	0	0	0	Killed	14.6
Thoracic												
Frozen	360	178	2.4	−70° C.	138	Excellent	0	0	0	0	Killed	15.2
Nutrient	380	16	3.0†	Simms X6	1	Excellent	0	0	0	0	Shock	12.8
	87	204	3.2	Simms X6	100	Excellent	0	0	0	0	Killed	15.2
	363	7	3.2	Simms X6	114	Excellent	0	0	0	0	Killed	10.8
Carotid artery:												
Homologous												
Frozen	27	18	2.4	−70° C.	16	Excellent	0	0	+	+	Killed	9.8
	61	22	1.7	−70° C.	25	Excellent	0	0	+	+	Distemper	9.8
	51	46	2.9	−70° C.	109	Good	+*	0	0	0	Distemper	15.2
	53	55	2.1	−70° C.	113	Occluded	+*	0	0	0	Killed	12.2
Nutrient	26	13	2.3	Simms X6	21	Excellent	0	0	+	+	Distemper	16.7
	63	15	1.8	Simms X6	31	Excellent	0	0	±	±	Distemper	9.8
	50	43	2.9	Simms X6	104	Occluded	+*	0	0	0	Killed	19.2
	52	50	2.1	Simms X6	168	Excellent	0	0	0	0	Killed	12.8
Autologous grafts	27	0	2.3	None	16	Excellent	0	0	0	0		
	26	0	1.5	None	21	Excellent	0	0	0	0		
	61	0	2.0	None	25	Excellent	0	0	0	0		
	63	0	1.7	None	31	Excellent	0	0	0	0		
	50	0	1.5	None	104	Excellent	0	0	0	0		
	51	0	2.9	None	109	Excellent	0	0	0	0		
	53	0	1.9	None	113	Excellent	0	0	0	0		
	52	0	1.9	None	168	Excellent	0	0	0	0		

*Moderate to large thrombus reducing or blocking blood flow through the graft.
†Subclavian artery implanted into graft.

tening of the eversion in many permitted some diminution of the constriction. In none of the grafts was the functional capacity altered by the minimal constriction present at the anastomoses.

Microscopic Appearance of the Grafts and Anastomoses.—This section deals primarily with the histologic changes observed at the suture lines rather than with those occurring in the actual grafts. The latter findings have been described in detail in other publications of ours.[24, 25, 26]

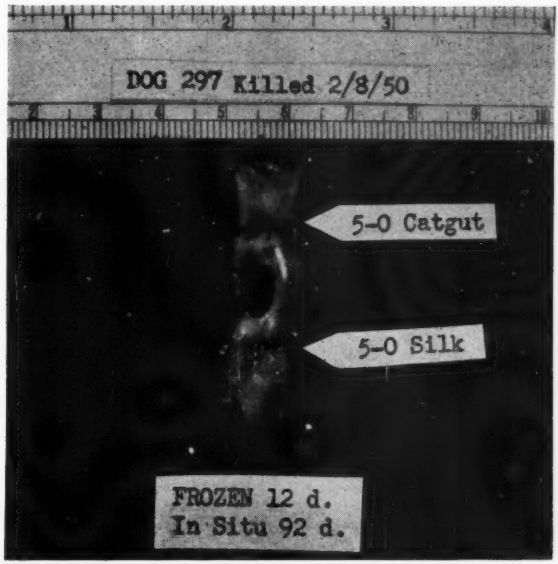
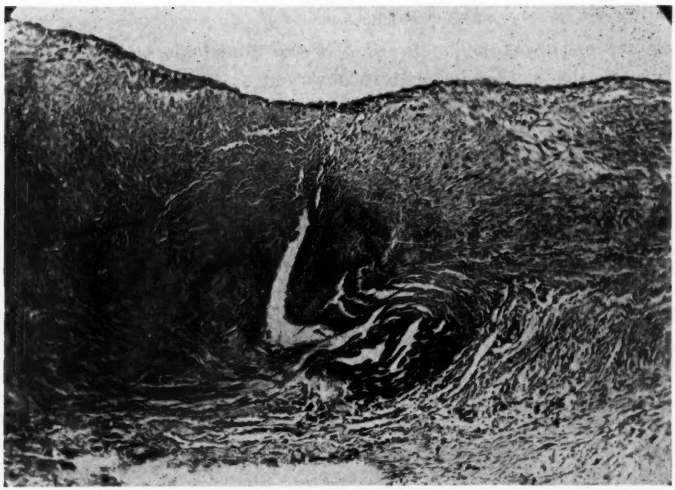
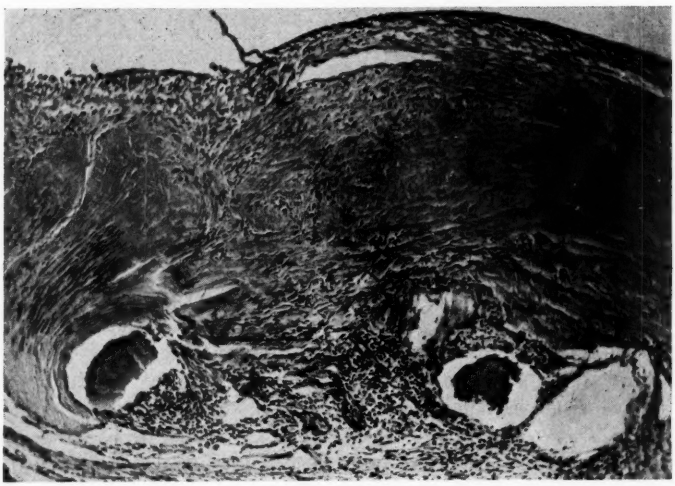


Fig. 3.—Graft obtained from the abdominal aorta and stored twelve days at −27° C., before implantation into the abdominal aorta of another dog for ninety-two days. There is an erosion of the intima in the midportion of the graft, but no thrombosis. The chromic catgut is not recognizable grossly, but the silk sutures are visible beneath the endothelium covering the distal anastomosis.

It will suffice to reiterate that all of the homografts, whether preserved by freezing or in a nutrient solution, and whether of aorta or carotid artery, undergo a slow degeneration during storage. The endothelium and many of the smooth muscle cells have disappeared by the time the graft is used, and usually within several weeks after implantation, even the residual cellular elements of the graft have disappeared. This process is somewhat slower in grafts stored in nutrient solution. The grafts become lined as well as invested externally by thick fibroblastic layers from the host within days, and after several months the persisting elastic and collagen framework of the graft itself are infiltrated with the new fibroblasts. Observations carried out for as long as two years following implantation reveal that the original elastic framework remains grossly intact, although some fragmentation of the fibers can usually be detected, whereas the remainder of the homograft has become replaced by fibrous tissue from the recipient animal.[26]



A.



B.

Fig. 4.—Photomicrographs of the suture lines of a carotid homograft stored twenty-two days at −70° C. and functioning for twenty-five days in another dog. (Hematoxylin and eosin, ×100.) *A*, The silk suture material is unaltered. A mild cellular reaction is still evident adjacent to the silk. Firm fibrous union and smooth endothelization has occurred. *B*, The chromic catgut is being removed by macrophages. A moderate cellular reaction surrounds the suture material. Firm fibrous union and smooth endothelization has occurred. The acellular frozen graft is visible to the right beneath the fibrocellular intimal zone derived from the host vessel.

The autologous graft, as represented by the segment of carotid transferred to the contralateral artery, revealed very few histological changes following transplantation.

Study of the anastomoses by histological preparations suggested that some of the early inflammatory response observed was evoked by the homograft, rather than by the suture material. Polymorphonuclear leukocytes appeared at the anastomosis and external surface of the graft within hours. At one day, there was noted a fresh thrombus in the wedge-shaped cleft on the luminal side of the anastomosis, produced by eversion of the edges of the vessels. The

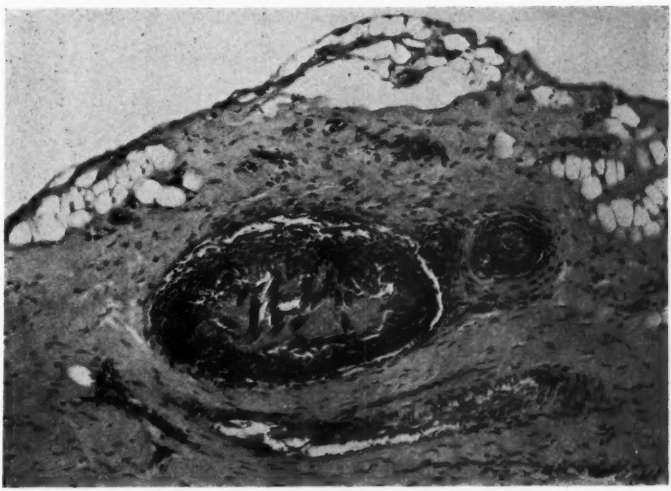


Fig. 5.—Granulomatous reaction surrounding silk suture in an autologous carotid graft, twenty-five days following anastomosis.

fibrin matrix of this plug served to allow bridging of the anastomosis by endothelium and fibroblasts from the host aorta within a week. Since the homografts were usually devoid of endothelium, a thickening fibrocellular layer developed over the anastomosis by two or three weeks, as the new intimal lining advanced toward the midzone of the graft from each end.

At the anastomosis, round cells and macrophages appeared within a few days, this time evoked apparently by the suture material which acted as a foreign body. In some specimens it appeared that the cellular response about the suture material was greater with catgut during the first week, but the differences often were not striking. Some individual variation in animals was noted insofar as cellular response to suture material. In some there was minimal reaction about both catgut and silk, whereas in others there was a moderate to marked inflammatory reaction about both (Fig. 4, *A* and *B*). This fact has been overlooked by many investigators studying suture materials by using each type alone in comparable groups of animals. After ten days to two weeks, the

inflammatory cellular reaction about the suture material usually diminished markedly. Macrophage activity was variable in the different animals, generally being most predominant about the catgut.

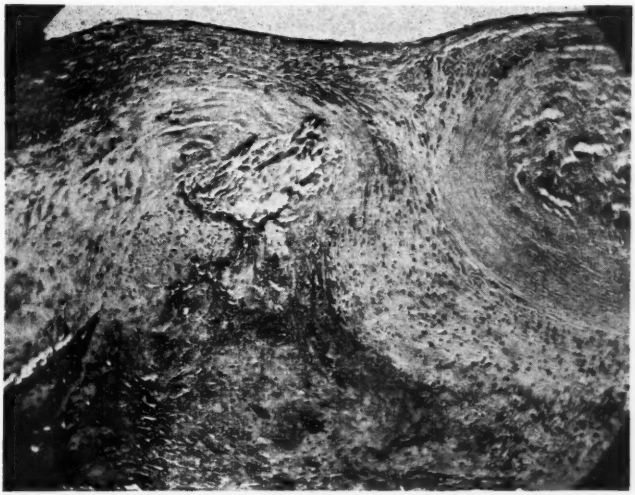
By one month the tissues about the silk were usually free of cellular reaction, but in some specimens, granulomas developed about the suture strands (Fig. 5). By this time, the tissues about the catgut were also free of cellular reaction except for scattered macrophages, and the suture, staining as hyaline basophilic material, appeared to be diminishing in size (Fig. 6). Firm healing

Fig. 6.—Anastomosis of carotid graft preserved fifteen days at 4° C. in a nutrient solution. At thirty-one days chromic catgut still remains beneath a fibrous union. The minimal cellular reaction consists mainly of round cells and macrophages.

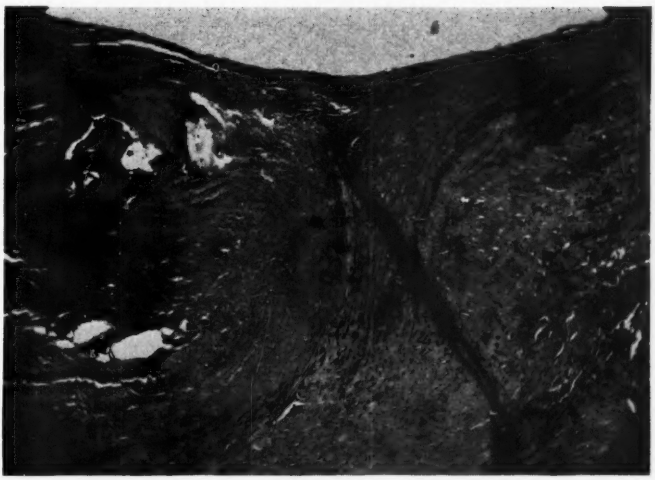
had occurred by fibrous union and a multilayered intima covered the anastomosis. The graft and normal aorta were compressed where eversion occurred, and at times appeared acellular at the point of approximation, where compression was greatest (Fig. 7, *A* and *B*).

During subsequent months, the status of the silk remained essentially unchanged. The catgut was recognizable without difficulty after eight to ten weeks in most specimens; moreover, in a few, the suture strand was only slightly altered at three months. After fragmentation and removal by macrophages had occurred, the site of the suture was identified only by a punctate fibrous scar.

Clinical Application.—Because of the satisfactory experimental results with fine medium chromic catgut as a vascular suture material, it was considered as safe for anastomoses of vessels in infants or children in whom growth is the major factor.



A.



B.

Fig. 7.—Photomicrographs of anastomoses of an abdominal aortic homograft, stored forty-five days at −27° C. and implanted for sixty-one days. (Hematoxylin and eosin. ×100.) *A*, At the silk suture line, there is excellent fibrous union and endothelization. The silk strands are unaltered, and there is little or no cellular activity about them. *B*, A fragment of chromic catgut remains in the graft at the left. Macrophages are engaged in removing this material. Excellent fibrous union and complete endothelization has occurred.

CASE REPORTS

CASE 1.—T. E., a white 21-month-old male infant, was admitted to Babies Hospital on Nov. 13, 1950, for special studies and possible operative repair of a coarctation of the aorta because of a progressive severe hypertension. The family history and past medical history were of no special interest. The child had never exhibited symptoms referable to the cardiovascular system, and had been followed closely in the pediatric clinic since the age of six weeks, at which time no cardiac murmur had been noted. However, at ten weeks, a questionable systolic murmur was noted. By the age of three months, the murmur was localized over the precordium, maximal in the left second and third interspaces. At this time, femoral pulses were not obtainable and the brachial blood pressure was 160-130/110. Laboratory studies, including chest film, electrocardiogram, Mazzini, blood culture, tuberculin, urinalysis, and fundus examination, were negative. The nonprotein nitrogen was 34 mg. per cent.

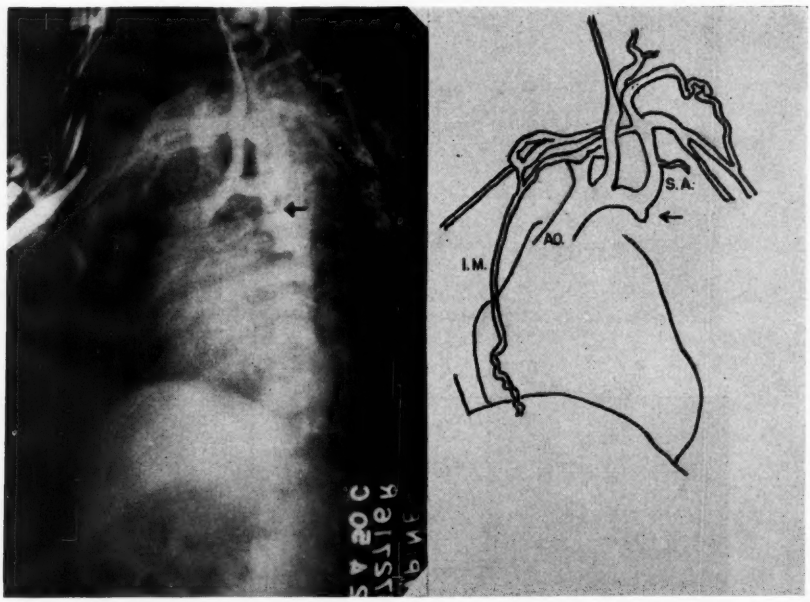


Fig. 8.—Retrograde carotid aortogram obtained in the right posterior oblique position. The obstruction in the aorta (*AO.*) is situated just distal to the left subclavian artery (*S.A*) as shown by the arrow. Note the dilated and tortuous internal mammary artery (*I.M.*) and other collateral arteries in this 21-month-old infant.

Brachial blood pressures were obtained at six-month intervals and revealed a progressive rise to the time of admission at which time it was 180/120. Physical examination was negative except for the loud precordial systolic murmur transmitted posteriorly and the absent femoral pulses.

Positive laboratory studies carried out in November, 1950, were limited to the cardiovascular system. Angiocardiogram and a retrograde carotid arteriogram revealed a complete stenosis of the aorta about 8 millimeters distal to the left subclavian artery with minimal collateral circulation (Fig. 8). No notching of the ribs was present. Through the cooperation of Dr. John Nickerson, a recording of the low frequency, critically damped ballistocardiogram of the patient was obtained under avertin anesthesia. The initial tracing confirmed the presence of a marked coarctation (Fig. 9, *A*).

On Dec. 8, 1950, operation was performed by one of us (R.A.D.). The coarctation was of the adult type, situated as visualized at about 8 mm. distal to the slightly dilated

left subclavian artery. A complete stenosis was at the site previously demonstrated. However, a very atretic cone-shaped segment of aorta constituted the 2 cm. of vessel distal to the coarctation. The left internal mammary and upper intercostal arteries were only slightly dilated and had minimal tortuosity, unlike those in our previous cases, the youngest of whom was nine years old. The ductus arteriosus was obliterated.

Although a fresh human iliac homograft was on hand, it was felt that every effort should be made to effect an end-to-end anastomosis. Accordingly, the upper four sets of intercostal arteries were sectioned and the distal aorta mobilized in its bed to below the

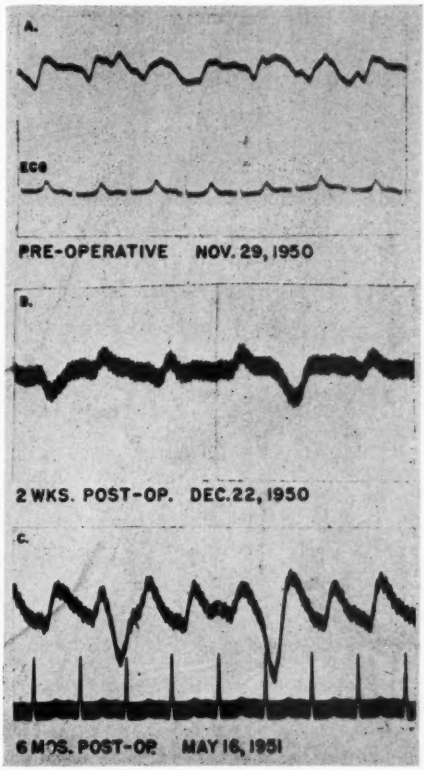


Fig. 9.—Ballistocardiograms obtained on the Nickerson bed with the infant anesthetized by aver in. *A*, Before operation, the J waves form a plateau in some complexes with a slow decline to the base line. The complete absence of K waves is characteristic of coarctation of the aorta. *B*, Two weeks after excision of the coarctation there is a more rapid down slope of the J waves with a trend toward K waves. *C*, Six months after operation, continued changes toward normal are evidenced by sharper J waves and fall below the base line. In some complexes, there are definite small K waves.

level of the sixth intercostal arteries. In this manner it was possible to carry out a satisfactory anastomosis without undue tension after excision of the atretic length of aorta (Fig. 10). A single row of interrupted horizontal mattress sutures of 00000 medium chromic catgut was used to approximate the cut edges. An additional row of simple interrupted catgut sutures were placed in the everted edges (Fig. 11). No constriction of any significance was present at the anastomosis.

We are indebted to Drs. Hugh Fitzpatrick and Sanford Weissman for obtaining continuous determinations of the pressures in the brachial and femoral arteries by means of

Lilly manometers, during operation, and on subsequent occasions. An electrocardiogram was recorded simultaneously. Early in the operation, with the patient under ether anesthesia, the brachial blood pressure was 130/80, whereas that in the femoral artery was 85/75 (Fig. 12). Immediately before repairing the coarctation, the pressures were 110/60 and 80/70, respectively, with a lag in the onset of the femoral pulse wave of 0.14 second. Once the aorta was repaired, and the clamps had been removed slowly, there was a decline in pressures to 90/50 in the arm, and 75/50 in the leg. However, distinct improvement in hemodynamics was reflected by the greatly increased pulse pressure in the femoral pressure,

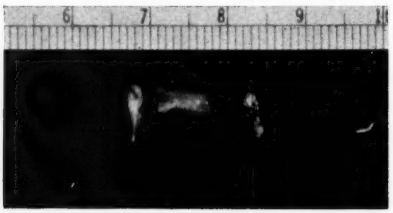


Fig. 10.—Excised coarcted segment of aorta. The proximal end faces to the left, with the ligamentum arteriosum on the superior surface at the site of the maximal stenosis.

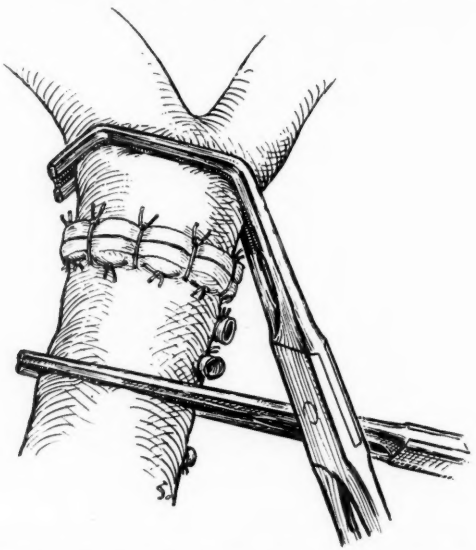


Fig. 11.—Completed anastomosis showing alternating interrupted horizontal mattress and simple sutures of 00000 chromic catgut. A straight Potts ductus clamp was used to occlude the aorta distally. The Beck clamp above permitted blood to flow into the subclavian artery during the procedure.

and in a decrease in pulse lag to 0.04 second. Two weeks later, pressures measured with the child under avertin anesthesia were 110/60 in the brachial artery and 95/50 in the femoral artery, with a pulse lag of only 0.04 second. At six months, again with the child under avertin anesthesia, these studies revealed the brachial pressure to be 120/70 and the femoral one to be 96/50. The pulse lag at this time was 0.04 second (Fig. 12).

The ballistocardiogram obtained two weeks following operation showed changes toward normal, namely, a sharper J wave and a tendency toward a K wave (Fig. 9, *B*). At six months, the J wave appeared still sharper, and a small K wave was developing (Fig. 9, *C*).

Convalescence was complicated by a slight hemothorax, corrected by a single aspiration. No tube had been employed for drainage. The patient left the hospital on the fifteenth day after operation with a brachial pressure of 120/80 as obtained by arm cuff.

Follow-up visits by the patient one and six months following date of operation revealed good weight gain. A diminishing systolic murmur was noted over the left chest. This was thought to be due to improved stream lining at the anastomosis. The pulses in the femoral and dorsalis pedis vessels were strong.

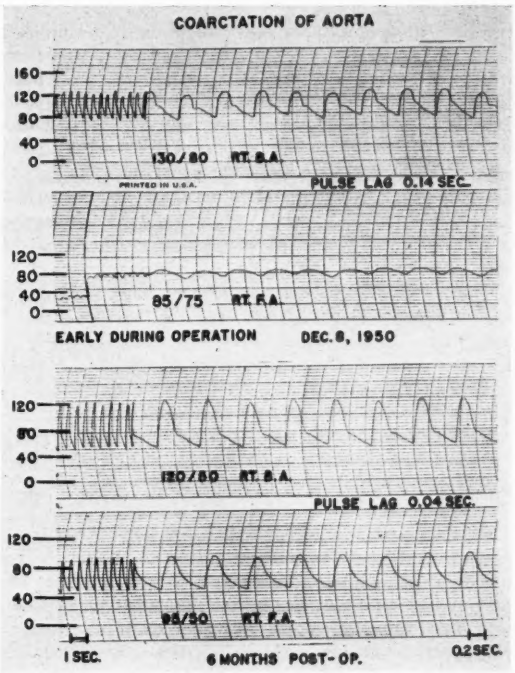


Fig. 12.—Simultaneous intra-arterial pressure tracings obtained with Lilly manometers. The upper two tracings demonstrate the pressure curves in the right brachial and right femoral arteries with the patient under ether anesthesia and before excision of the coarctation. Note the difference in onset of the waves of 0.14 second and the greatly dampened pressure in the leg. The lower two tracings obtained with the child under avertin anesthesia six months after excision of the coarctation reveal a pulse lag of only 0.04 second and greatly improved circulation in the lower extremity.

Case 2.—W. T., a white 4-year-old boy, was admitted to Babies Hospital on May 21, 1951, with the diagnosis of portal hypertension. The child had had an omphalitis at the age of two weeks, followed at six weeks by a septic arthritis of the left shoulder. The inflammation subsided under antimicrobial therapy and his subsequent general state of health was good until the onset of fever and a head cold early in March, 1951.

Two days later, he suddenly vomited a large quantity of blood and was admitted to another hospital in shock. The only other significant information in the history recalled a fall on the abdomen a week before, with residual tenderness for several days. At time of admission March 6, 1951, his spleen was felt 2 cm. below the costal margin, but the liver was not palpable.

Blood studies revealed red count of 2.88 millions per cubic millimeter; leukocyte count, 3,400 cells per cubic millimeter, with 89 per cent polymorphonuclear cells, 10 per cent

lymphocytes, and 1 per cent monocytes. The platelet count was 130,000. Bleeding time, clotting time, clot retraction, and red cell fragility were normal. Volume index was 0.93 and the icteric index, 7.4 units. Roentgenograms of the chest, skull, and long bones, urinalysis, and serological test were negative. Esophagram did reveal filling defects interpreted as varices, however.

Treatment by multiple transfusions was accompanied each time by marked splenic enlargement. The patient was discharged March 16, 1951, but had to be readmitted May 8, 1951, because of massive hematemesis. This time splenomegaly was not noted. Multiple transfusions were administered, totaling 1,500 cubic millimeters.

The local physician displayed keen clinical insight into this problem as demonstrated by his investigations and management. The child was discharged May 17, 1951, and admitted to Babies Hospital on May 21, 1951, for surgical treatment of portal hypertension, resulting from an extrahepatic block caused in all probability by the omphalitis. Physical examination this time revealed a palpable sharp liver edge, and enlarged spleen felt 10 cm. below the costal margin.

Laboratory studies: Hemoglobin, 9.7 Gm.; red cells, 3.12 millions per cubic millimeter; leukocytic count, 5500. Polymorphonuclear cells, 71 per cent; lymphocytes, 24 per cent; monocytes, 2 per cent, and eosinophiles, 3 per cent. Normal red cell fragility was found. Platelet count was 112,000, and reticulocytes, 2.0 per cent. Alkaline phosphatase was 2.9 Bodansky units; phosphorus, 4.5 mg. per cent; serum albumin, 4.6 Gm., and globulin, 2.2 Gm. Nonprotein nitrogen was 31 mg. per cent. Sedimentation rate 15 mm. per hour. Urinalysis negative. Chest film and excretory urogram were negative. The esophagram again showed varices. Direct Coombs test was negative. Prothrombin time was 17.1 seconds (normal fifteen seconds). Bromsulfalein retention test showed serum concentration of 29 per cent at five minutes, and 1 per cent at thirty minutes. Glucose tolerance test was normal. Blood volume determination on May 26, 1951, revealed plasma volume of 1,330 c.c., red cell mass of 550 c.c., and hematocrit of 29.1 per cent. After two transfusions of 150 c.c. each, the blood volume increased to a plasma volume of 1,350, red cell mass of 710 c.c., and hematocrit of 34.5 per cent.

On June 6, 1951, operation was performed by one of us (R.A.D.). Through a left thoracoabdominal approach, the large spleen was exposed, and the splenic vessels isolated. The splenic artery was divided and pressure exerted on the spleen to express the red cells into the general circulation. The dilated splenic vein was then divided at the bifurcation at the hilus. A springy rubber-shod Bulldog serrafin was used to occlude the proximal end until it was time to perform the anastomosis. The pressure in the splenic vein was 370 mm. of water. A large left renal vein was mobilized in the renal pediele, and a small curved spring clamp with fine teeth* was used to isolate a 1.5 cm. segment, on the anterosuperior surface of the vein. With renal venous outflow thus unimpeded, a 1 cm. longitudinal incision was made in the segment, and the end of the splenic vein was brought into approximation. An everting anastomosis was accomplished with the use of six interrupted mattress sutures of chromic catgut. When the shunt was opened, free blood flow occurred from the splenic vein into the renal vein. Digital closure of the shunt caused a prompt rise in portal pressure of 100 to 120 millimeters of water to the previous level of 370 (Fig. 13). The portal vein was not accessible to examination, but the liver had a normal appearance. Biopsy of the liver revealed a mild cirrhosis, however.

A fine polyethylene catheter, introduced through the inferior mesenteric vein to the splenic vein, was brought out through the abdominal incision for regional heparinization of the portal blood passing through the shunt. Postoperatively, heparin in a dosage of 25 mg. per 500 c.c. of 0.85 per cent saline was administered through the catheter at a rate of 10 to 45 drops per minute for six days.

Convalescence was completely uneventful. A follow-up visit six weeks after operation revealed that the child was very active and had gained several pounds in body weight since discharge from the hospital on the fifteenth postoperative day.

*Manufactured by Bruno Richter, Glen Ellyn, Ill.

CASE 3.—J. B., a white 5½-year-old girl, was admitted to Babies Hospital July 11, 1951, for special studies and possible operative repair of a coarctation of the aorta. She had been referred by her local physician to the Congenital Heart Clinic in April, 1951. Previous studies had revealed the characteristic physical signs of coarctation. Her brachial blood pressure had been noted as being 200/100. The chest film had been unusual in that there was moderate cardiac enlargement. For this reason, it was felt wise to plan an early admission.

In the hospital, a brachial hypertension of 190/96 was noted. The femoral pulses were weak and no dorsalis pedis pulses were felt. Oscillometric readings of one unit were obtained at the calf. A short harsh systolic murmur was heard over the base of the heart, transmitted posteriorly high on the left side of the chest.

Routine laboratory studies of the blood were normal, as was urinalysis. The roentgenogram of the chest and esophagram revealed enlargement of the left auricle and ventricle. An angiocardiogram on July 17, 1951, demonstrated a marked coarctation one centimeter distal to a dilated left subclavian artery. The aortic arch was shown to be very hypoplastic beyond the innominate artery to the level of the coarctation. There was a moderate poststenotic dilatation of the aorta. Difficult to interpret was the retention of diodrast in the left auricle which suggested impaired outflow from this chamber (Fig. 14). The ballistocardiogram revealed the absence of a K wave, characteristic of coarctation (Fig. 15).

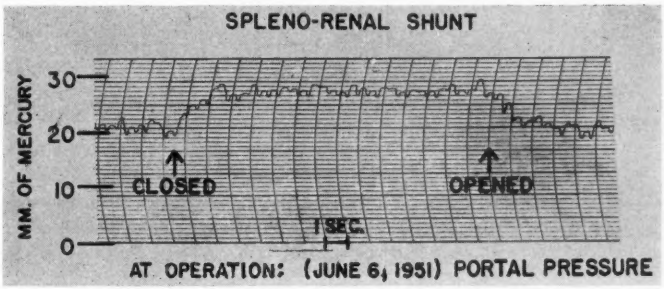


Fig. 13.—Portal pressure obtained through a catheter introduced into the inferior mesenteric vein. When the spleno-renal shunt was occluded, there was an immediate rise in pressure in the portal system. A prompt fall occurred when the shunt was again opened.

On July 20, 1951, operation was carried out by one of us (R.A.D.), after digitalization of the patient. The stenotic segment was short and situated as visualized. The aortic arch appeared hypoplastic, whereas there was a slight poststenotic dilatation below the coarctation. The fibrous ligamentum arteriosum was divided, as were the first two sets of intercostal arteries. A one centimeter segment of aorta at the coarctation was excised and a very satisfactory end-to-end repair effected as in Case 1 (Fig. 11). Examination of the specimen revealed the stenosis to be complete.

The pericardium was opened and the left auricle was examined. It did not appear to be greatly dilated, but some turbulence was noted. A systolic thrill was felt over the posterior aspect of the left ventricle. Even minimal manipulation of the heart produced arrhythmia despite topical procaine, so further investigation was thought best deferred until cardiac catheterization could be carried out.

Postoperatively, the femoral and dorsalis pedis pulses were very strong. The brachial blood pressure fluctuated between 116/80 and 160/110 during the first two weeks, as is often observed. A few days following operation the patient began to have diffuse low abdominal discomfort. Moderate fever and a leukocytosis developed, with a slowly rising polymorphonuclear count. The pain varied in intensity, but did not subside during a week of observation, and finally on July 31, 1951, exploration was performed by Dr. Robert Hiatt and one of us (R.A.D.). There was a small amount of clear yellow fluid in the peritoneal cavity. The small bowel was edematous and hyperemic. The marked hyperemia was noted

in the colon and parietal peritoneum as well. All of the mesenteric lymph glands were very enlarged. The appendix was normal in appearance and there was no evidence of mesenteric or retroperitoneal bleeding. Following this operation, the abdominal symptoms subsided rapidly. It was not clear whether the mesenteric adenitis was primary or secondary. The marked hyperemia and the edema of the bowel were unusual, and the cause uncertain.

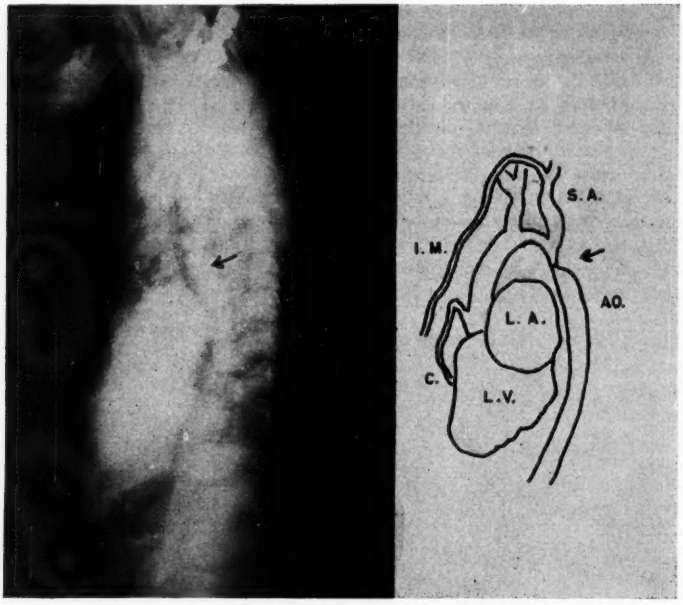


Fig. 14.—Angiocardiogram obtained of the patient in the right lateral position. The dilated left auricle (*L.A.*) is well filled with diodrast, as is the left ventricle (*L.V.*). The aortic arch is moderately narrowed beyond the innominate artery to the level of the actual coarctation (arrow), but slightly dilated below this (*AO.*). The dilated left subclavian artery (*S.A.*) coursing caphalad from the area of the stenosis, as well as the dilated, tortuous internal mammary artery (*I.M.*) are well visualized. Note the coronary artery (*C.*) anterior to the root of the aorta.

DISCUSSION

It has not been the purpose of this study to discredit fine braided silk as a vascular suture material. Indeed, the results here would confirm that it is highly satisfactory, at the test of time has amply shown. On the other hand, this work has confirmed certain previous observations as to the very satisfactory performance of chromic catgut, when used properly.

As pointed out by Bower and Pearce,[14] many of the earlier comparisons of catgut and silk were unfair because of differences in size of the suture, type of needle used, and because of the criteria for acceptability. Even Whipple[12] called attention to greater trauma to tissues when catgut was used because of the larger needle. He suggested also that the early inflammatory response about the catgut suture always meant low grade infection. Certainly, the 00000 and 000000 catgut swaged on the needle creates no greater trauma than do the finer sizes of silk. From the extensive studies of Howes and associates,[7-11] the

consistent curves of tensile strength of catgut in tissues did not support the contention that the polymorphonuclear response was on the basis of infection. Our own tissue culture studies of segments from the region of the catgut anastomosis did not show any sign of baterial infection or contamination. Jenkins and Dunham[27] have demonstrated the ability of the irritating water-insoluble hydrocarbons from the tubing fluids of both boilable and nonboilable catgut to elicit a strong polymorphonuclear reaction even when present in great dilution.

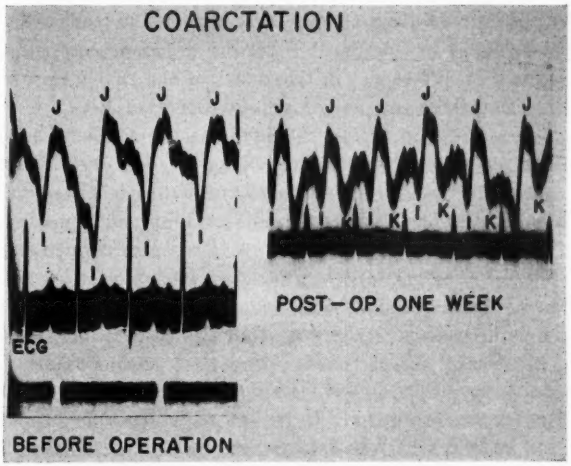


Fig. 15.—Ballistocardiogram before operation reveals the absence of a K wave which is characteristic of coarctation of the aorta. The record obtained one week after resection of the coarctation shows well-developed K waves.

They suggest that the routine technique employed in many operating rooms in preparing sutures for use is often inadequate to remove much of this fluid which is in itself adequate to explain much of the early tissue irritation. The manufacturer emphasizes the fact that precise and proper preparation of catgut, whether boilable or nonboilable, is essential in the operating room to insure ease of handling and uniformity of strength. Soaking too long in water may markedly reduce tensile strength. We admit that these factors may have been at fault at times in our own handling of this material.

The experiments by Howes[7-11] and his associates carefully analyzed the physical characteristics of catgut in various tissues, and compared this material with equivalent sizes of silk under certain circumstances. They noted a more intense inflammatory response with chromicized catgut than with plain, and showed that the time for complete loss of strength of both types of catgut approximated the time of absorption. Hence, for "20 day" chromic catgut, the complete loss of strength occurred on the eighteenth to twenty-first days. Once absorbed, no tissue reaction remained and scar formation was minimal. They observed a polymorphonuclear response with silk within forty-eight hours, as did we. Giant cells of the foreign body type were observed from the sixth day, being present thereafter as long as the silk remained. In addition, we found,

not infrequently, a granuloma developing about silk strands (Fig. 5). While the petrolatum used to lubricate the silk at time of operation was considered as a possible cause for the granulomatous reaction, this has been observed with untreated silk sutures. In this regard, both Large[28] and Rosenberg and associates[29, 30] have reported on granulomas caused by the waxes used by the manufacturer to produce a frictionless finish on cotton and silk sutures.

Jenkins and co-workers[31-34] recently carried out an extensive analysis of several sizes of plain and chromic catgut marketed by ten different manufacturers. In a follow-up of over three years, they noted variability in the performance in the tissues of comparable gut of different companies. This was believed due in part to differences in treatment of the raw catgut at the factory. As a result they suggested the use of pepsin digestion tests for more accurate classification. Although the term "20 day" has been abandoned, such terms as "Type C" or "medium chromic" are being used to describe catgut such as was used in our experiments. The studies of Jenkins and associates showed such material to retain its tensile strength for ten to fifteen days, and to remain in the tissues for from three to six months, as confirmed by our observations. They noted more reaction to plain than chromicized catgut, in contrast to the findings of Howes and associates. This finding by Jenkins was later thought by him to be related to the irritation from the tubing fluid rather than to the type of gut used.[27]

Fine sizes of catgut were found most desirable by Howes and Jenkins, since the inflammatory reaction appeared to be less with the finer strands. The holding power of the tissues was found to be less in most instances than that of a 000 catgut suture line. The exception to this was found in fascia, a very condensed connective tissue. This naturally raised the question as to the strength of catgut as an arterial suture. Dry 00000 medium chromic catgut has been said to have a tensile strength of 560 grams.[18] Anastomoses made with this material were found by Sako and associates[18] to leak at pressures below those observed with silk. It should be noted, however, that the values obtained by them on the various days postoperatively were from single animals, and, consequently, these data are not fully conclusive. The delayed fatal hemorrhage observed by these authors with the everting technique and catgut is at variance with the success enjoyed by us and others.[19, 20] Their similar difficulties with the everting technique and silk suggest that the type of suture material was not a primary factor.

Howes and co-workers demonstrated that infection, hemorrhage, and tissue necrosis increased the early inflammatory reaction which hastened absorption, and hence caused a rapid loss of tensile strength regardless of chromicizing or size of the suture. In the field of vascular surgery, these are the same factors which have predisposed to hemorrhage and thrombosis regardless of suture material. There would seem to be little excuse for abandoning certain strict rules of vascular suture technique which demand avoidance of contamination, poor hemostasis, and careless handling of tissues. Certain vascular surgeons have expressed a fear to use catgut because of possible empyema, and others a desire to reinforce the catgut line with interrupted silk sutures.

In animals the use of interrupted silk sutures, when growth of the vessel is involved, has been found very satisfactory. However, the experiments carried out in baby pigs revealed that, after full growth had been obtained, anastomoses made with continuous catgut had shown a similar increase in size to those made with interrupted silk. In contrast, those made with a continuous silk suture technique showed little or no increase in diameter. Others, however, have considered significant increase in size of the anastomosis possible when a continuous silk suture is employed in a growing animal.[17, 21, 35] We noted less constriction at the catgut anastomosis after several weeks than at the silk line when considering the degree of constriction which had been present at time of operation.

The incidence of thrombus formation at the proximal suture line must be analyzed, especially since we found small mural thrombi in three instances, moderate sized in two, and complete thrombotic occlusion in two, among the twenty homografts. It is difficult to evaluate thrombus formation when homografts are used, since this incidence is no greater than that which we observed in a large series of aortic homografts implanted with silk alone.[24, 25, 26]

In our series of over seventy-five implanted aortic homografts in which 00000 arterial silk alone had been used for both suture lines, post-mortem examination has now been carried out in over half of these animals. It was noted that mural thrombosis most frequently began at the proximal suture line or in the midportion of the graft as in the group being reported here. In all instances the smaller thrombi were rapidly endothelized and became so well organized as to be identifiable only by microscopic examination.

In the carotid group it appeared that the age of the graft and inside diameter were more important factors in thrombus formation than how the grafts were stored or what suture material was used. It seems of further significance that no thrombosis was encountered in the eight carotid autografts. This superiority of the autocraft agrees with previous studies of grafts in small arteries.[36] In a further attempt to compare catgut and silk in regard to incidence of thrombosis we again refer to the studies by Sako and associates.[18] With 000000 silk used for a single end-to-end anastomosis of the aorta by dogs, there were eleven incidences of thrombi among thirty noneverted suture lines, and ten among twenty-six everted anastomoses, or an incidence of 35 to 40 per cent. With 00000 catgut, there were two instances of thrombus formation among ten noneverting anastomoses performed with chromic gut and none among three noneverting lines made with plain gut, or an incidence of 9 to 20 per cent. While statistically not suitable for quantitative comparison, there did not appear to be any greater tendency or catgut to cause thrombosis.

With regard to the clinical cases, we have usually felt that the optimum time for repairing a coaretation of the aorta is in the early teens when most of the aortic growth has been accomplished and when little sclerosis is present in the vessel. The clinical recognition of coaretation in infants and young children has not been very frequent apparently,[37-39] and reports of operation on young children and infants have been rare.[39] Our previous experience with a continuous everting horizontal mattress suture of 00000 braided silk in two

children 9 years of age indicated that only partial correction of the defect may have been effected, since significant hypertension was observed subsequently. Once operation was indicated by the rapidly progressive hypertension of the 21-month-old infant, and cardiac enlargement in the 5-year-old girl, we elected to use the suture material which has appeared to cause the least late tissue reaction and scar formation, according to experimental studies.

Of the tests, the low frequency critically damped ballistocardiograph deserves mention in regard to cases of coaretation. As developed by Nickerson,[40] it differs considerably from the Starr type. The lack of overshoot allows a characteristic pattern to be demonstrated by the patient with coaretation which differs greatly from that of a normal individual.[41-45] Postoperative checks of this pattern as well as of stroke volume and cardiac output have given us valuable clues as to the effectiveness of various types of repair.

Of similar value have been the records of arterial pressures obtained directly from the brachial and femoral arteries before and after surgery. The return toward normal of the pulse lag, contour of the femoral pulse wave and arterial pressures has been charted in a number of cases by us and others.[46-49] The data obtained in our other cases of coaretation will be published in a separate report.

In general, it may be said that end-to-end repair is by far the best method of correcting a coaretation in the adult, and probably the only completely satisfactory method in the growing child. Experience in growing animals and human beings has shown that anastomosing the subclavian artery to the distal aortic stump or interposing a preserved homograft[50] may result in a partial coaretation, after full growth has occurred.

Among the cases of portal hypertension, which have been referred to us, the number of children has been surprisingly large. The usual causes have been cavernous transformation of the portal vein, thrombosis in the portal system, and schistosomiasis. Here, again, there is a distinct effort made to produce an anastomosis which can enlarge as the child grows. Whether catgut or silk is employed for anastomoses in children, one should rely on interrupted sutures as being most likely to allow maximal growth at the suture line, and certainly as the safest technique with catgut.

SUMMARY

Fine sizes of braided silk and medium chromic catgut were used to implant vascular grafts into twenty dogs. By using both suture materials in the same animal, a comparative study was possible. The anastomoses were examined after from one to one hundred and sixty-eight days.

Grossly, the chromic catgut began to fragment in about four weeks. At times the fibrosis at the silk suture line seemed greater than that observed at the catgut anastomosis. Occlusion of some of the grafts by thrombosis was believed related to the use of homografts in these dogs, rather than to the type of suture material. Microscopically, the early cellular reaction about the catgut was greater than that about the silk in some specimens. In others, comparable but varying degrees of reaction were found about both types of suture

material. In a few weeks, excellent fibrous union occurred in all instances. Residual fragments of catgut were observed for several months. Occasionally, granuloma formation was noted about the silk strands.

The use of interrupted 00000 medium chromic catgut sutures for major vascular anastomoses is reported in three children. In two of them, aged 21 months and 5½ years, a coarctation was excised and end-to-end aortic anastomosis carried out. In the other, aged 4 years, a spleno-renal shunt was performed. In all, the clinical result has been very satisfactory to date.

We wish to thank J. A. Deknatel and Son, Inc., and Ethicon Suture Laboratories for their generous cooperation. In addition, we wish to acknowledge the assistance rendered throughout by Miss Daisy Mapes, R.N., and her assistants; the technicians in the Surgical Pathology Laboratory; and Dr. Hugh Fitzpatrick, Dr. Sanford Weissman, and Dr. John L. Nickerson.

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